AFRL-ML-WP-TR-1998-4116

HYDRAULIC FLUIDS AND SEALS WORKSHOP PROCEEDINGS

Materials and Manufacturing Directorate
Air Force Research Laboratory
Wright-Patterson AFB, OH 45433-7734

MARCH 1998

FINAL REPORT FOR PERIOD 17 MARCH 1998 – 18 MARCH 1998

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MATERIALS & MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7734

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Symposium for conversion from MIL-H-5606 to MIL-H-83282 and MIL-H-87257 and for current hydraulic fluids development activities

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13. ABSTRACT *(Maximum 200 words)*
The Hydraulic Fluids and Seals Workshop was presented by the Materials and Manufacturing Directorate of the Air Force Research Laboratory in order to disseminate information about military hydraulic fluid changes and developments. The main showcase of the workshop was the transition from MIL-H-5606 to MIL-PRF-83282 and MIL-PRF-87257 operational hydraulic fluids. Other topics included future hydraulic system development, seal compatability testing, the search for a barium corrosion inhibitor replacement in the preservative oils, MIL-PRF-6083 and MIL-PRF-46170 which could be used in the operational fluids negating the need for the preservative oils, biodegradable testing for the operational hydraulic fluids, the development of the non-flammable hydraulic fluid, MIL-H-53119, the amount of water a hydraulic fluid can hold before causing ice in hydraulic fluid and pump testing of the operational hydraulic fluids to see if purifiers will degrade pump life.

14. SUBJECT TERMS

Fire Resistant Hydraulic Fluid	Military Hydrualic Fluid
Polyalphaolefin	Red Oil
Synthetic hydrocarbon	

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Hydraulic Fluid and Seals Workshop

The Materials Directorate of the Air Force Research Laboratory (AFRL/ML) sponsored the Hydraulic Fluids and Seals Workshop which centered around the transition from MIL-H-5606 to MIL-PRF-87257 hydraulic fluid but also included discussions about future hydraulic systems and future developments in hydraulic fluids. Of the 13 papers presented, 9 of them were presented by MLSC, MLSA, MLBT or MLBT contractors. Other presenters included Boeing, Oklahoma City Air Logistics Center and the Navy. Most of the papers or their contents have been presented at Society of Automotive Engineering A-6 meetings over the last several years. The other papers are also available in the public domain but are not conveniently compiled for the user. Approximately 90 people attended, including representatives from the United Kingdom, Canada and Germany. The addresses of the attendees plus those who have requested a copy of the proceedings are included at the back of the report.

Hydraulic Fluid and Seals Workshop Agenda
17-18 March 98

17 Mar

8-9 am Registration

9 am Welcoming Remarks, Bob Rapson, AFRL Materials Directorate

9:15 Hydraulic Fluid Background, Development and Transition, Ed Snyder, Lois Gschwender, Shashi Sharma and Stephanie Flanagan, AFRL Materials Directorate

1200 Lunch

13:30-16:30

B-1B Testing of MIL-H-87257, Jimmy Schmidt, Boeing, Shashi Sharma, AFRL Materials Directorate

Hydraulic Systems Future, Jimmy Schmidt, Glenn Anderson, Boeing

C-135 Testing and Transition, Pat Donahay, OC-ALC

Seal Material Validation, Al Fletcher, AFRL Materials Directorate, John Pulsifer, North Island

Hydraulic Fluid and Seals Workshop Agenda
17-18 March 98

18 Mar

8-9 am Registration

9 am

Future Hydraulic Fluid Development

Biodegradable Hydraulic Fluid, Rich Sapienza, METSS

Barium-free, Corrosion Inhibited Hydraulic Fluid, Ken Heater, METSS

Non-Flammable Hydraulic Fluid, Lois Gschwender, AFRL Materials Directorate

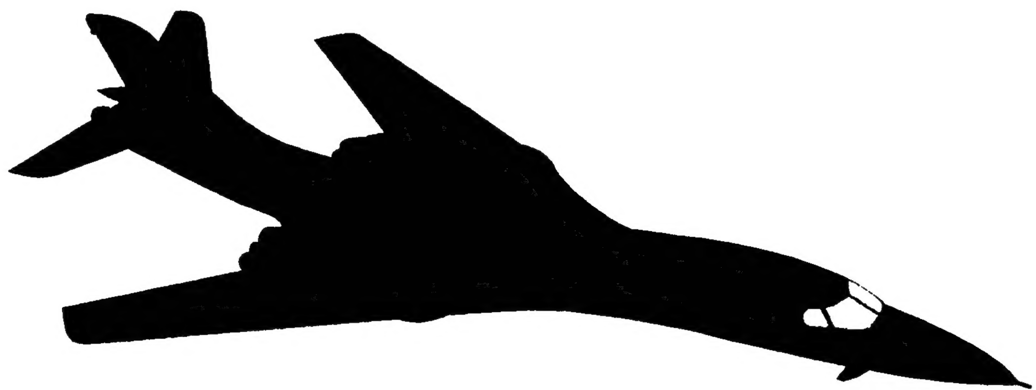
Moisture Levels Causing Ice in Hydraulic Fluid, Stephanie Flanagan, AFRL Materials Directorate

Hydraulic Fluid Purification, Ed Snyder, Shashi Sharma, AFRL Materials Directorate

12:00-13:30 Lunch

13:30-16:00 Discussion or Tours

MIL-PRF-87257
Fire Resistant Hydraulic Fluid



Lois Gschwender, Carl E. Snyder,
Shashi K. Sharma and Stephanie Flanagan

Wright-Patterson AFB

MIL-PRF-87257
Fire Resistant Hydraulic Fluid

Outline

- **Background - Ed Snyder**
- **MIL-PRF-87257 Development - Lois Gschwender**
- **Pump Testing - Shashi Sharma**
- **Transition - Stephanie Flanagan**

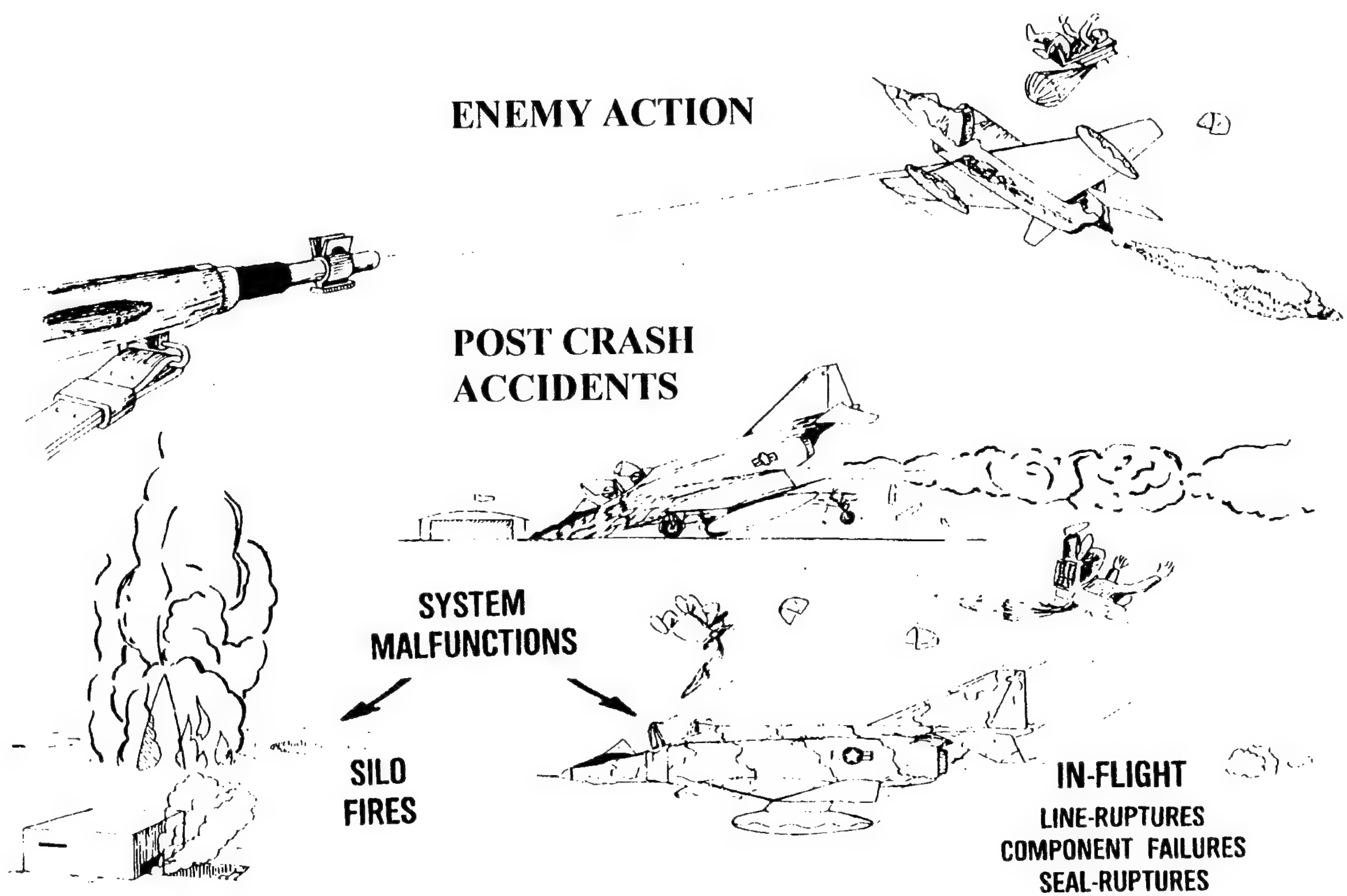
Outline

- Hazards
- Fluids
- Flammability Data
- About Fluids
  - AS1241
  - MIL-PRF-83282
  - MIL-PRF-87257
- MIL-PRF-83282 Aircraft Evaluations
- Summary

Fire Resistant Hydraulic Fluids

- **Hazards Associated with Hydraulic Fluid Fires are Well Known**
  - **Significant History of Fire Losses**
    - **High Pressure Systems ($\leq$ 5000 psi)**
    - **Wide Variety of Ignition Sources**
      - **Hot Surfaces**
        - **Brakes**
        - **Engine Nacelles**
      - **Shorted Electrical Wires**
      - **Gunfire**

HYDRAULIC FLUID IGNITION SOURCES



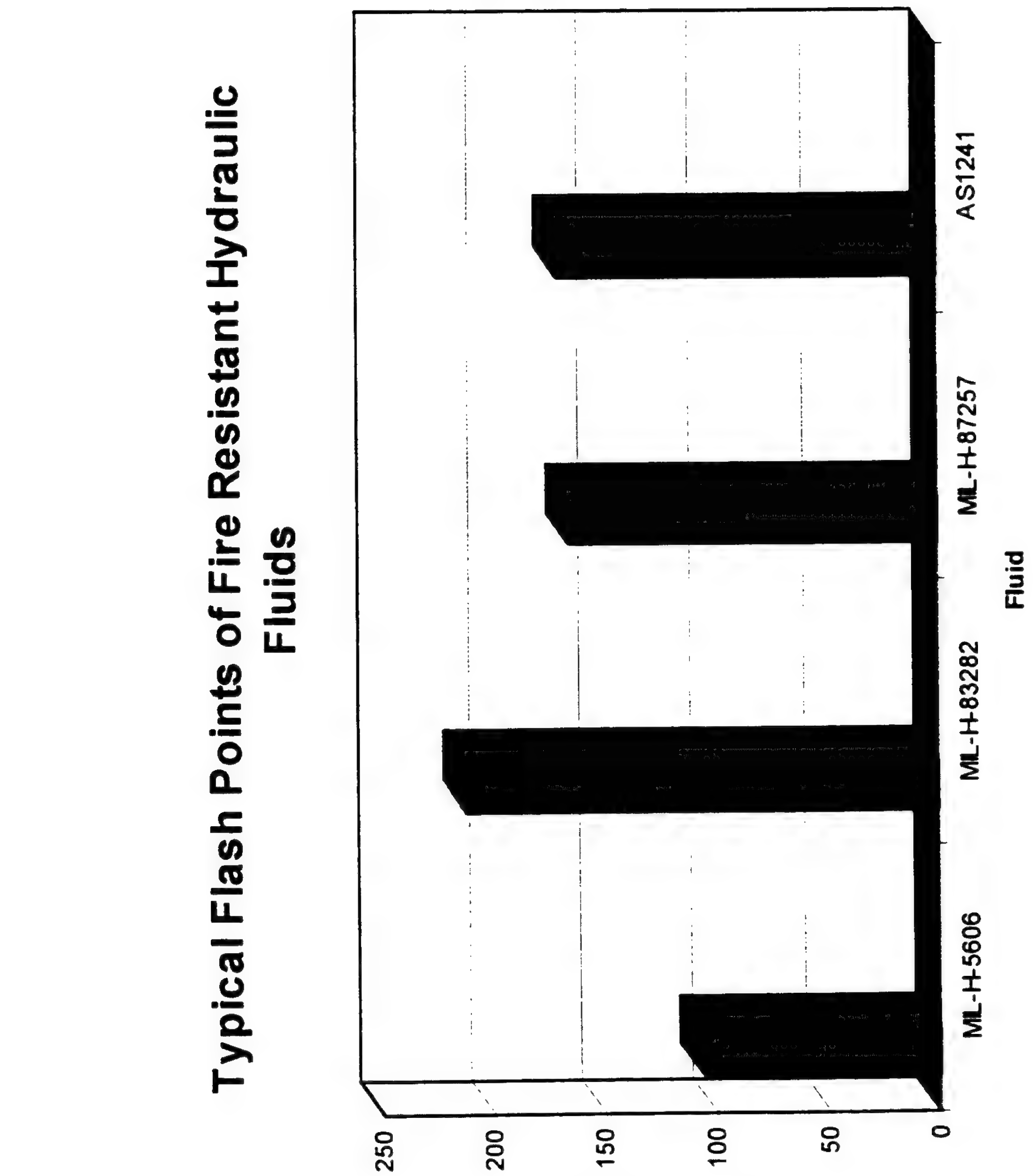
Three fire resistant hydraulic fluids

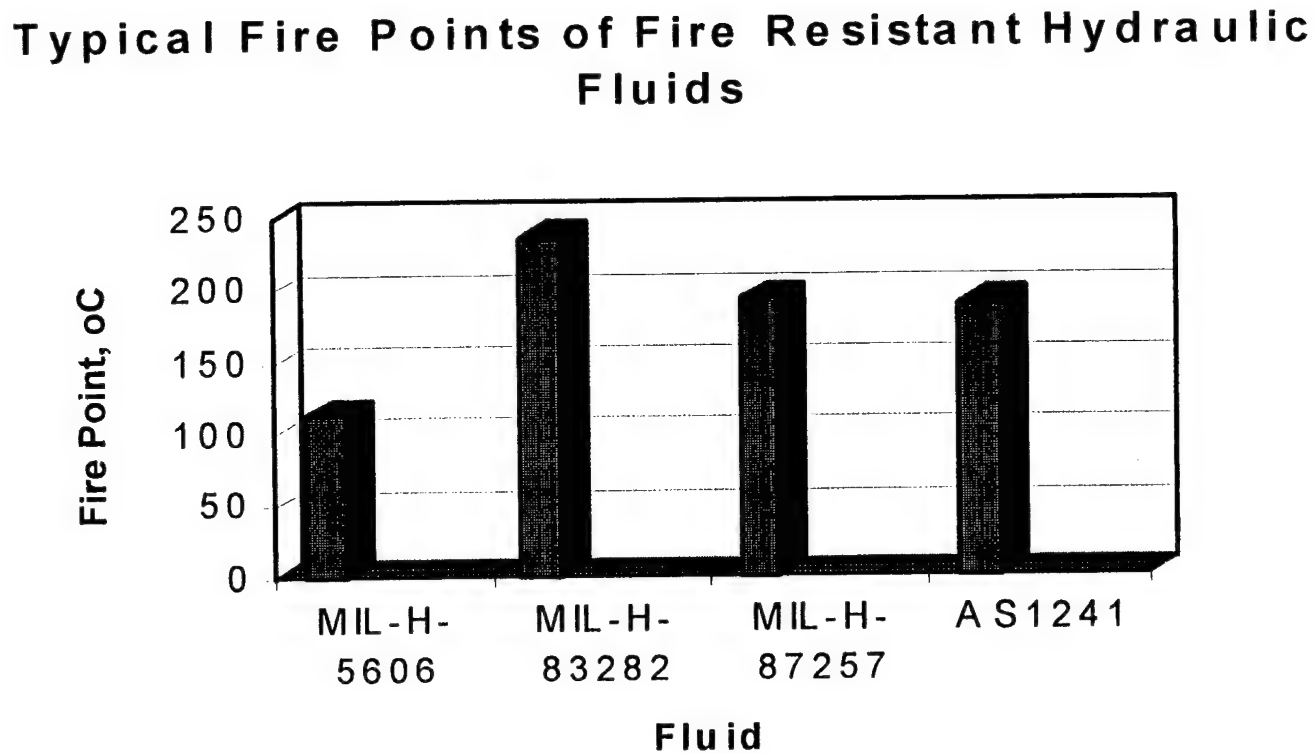
- AS1241 - Phosphate ester
- MIL-PRF-83282 - Synthetic hydrocarbon, polyalphaolefin (PAO), H-537
- MIL-PRF-87257 - Synthetic hydrocarbon, polyalphaolefin (PAO), H-538

Background

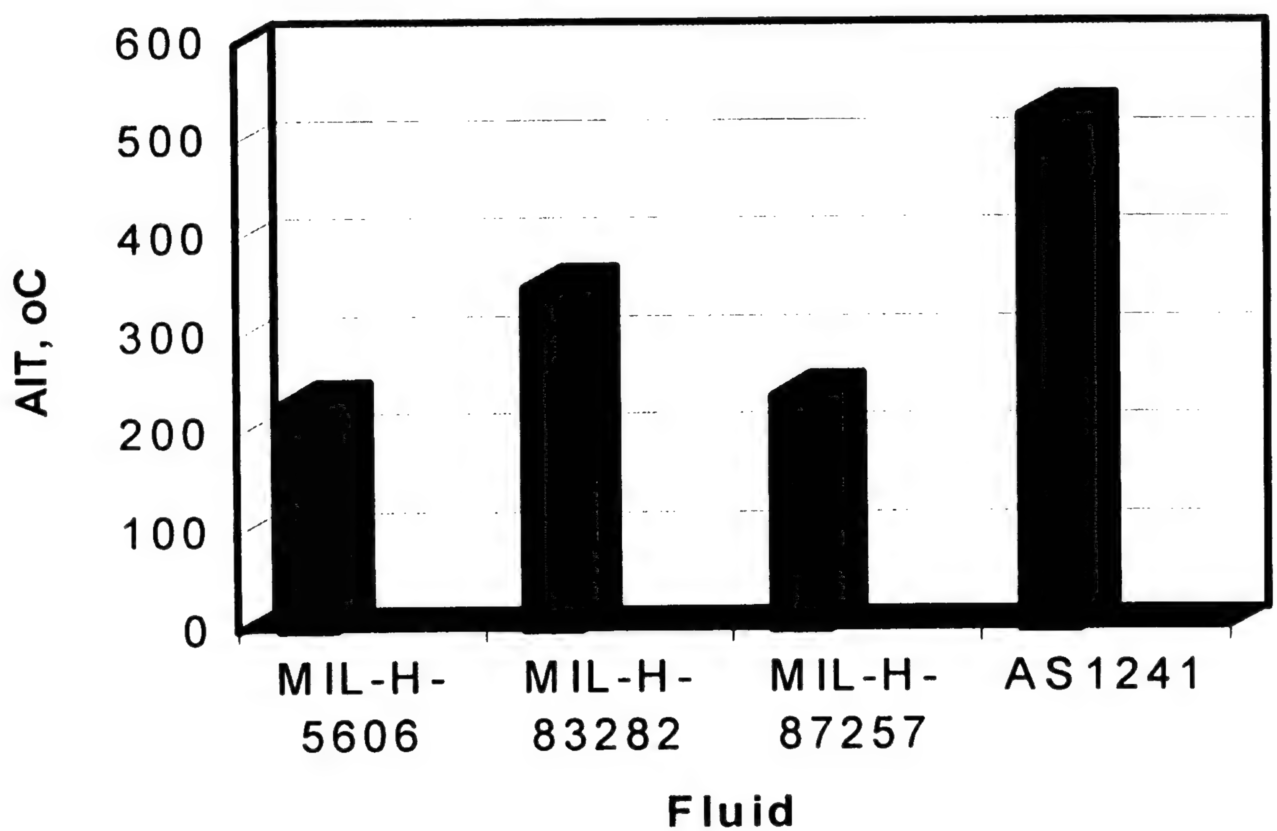
- MIL-H-5606 first aerospace hydraulic fluid
- Commercial aircraft converted to AS1241 in mid 1950's - military did not convert
- Military aircraft partially converted to MIL-PRF-83282 in 1970's and 1980's - some still using MIL-H-5606
- Military aircraft using MIL-H-5606 are converting to MIL-PRF-87257

Typical Flash Points of Fire Resistant Hydraulic Fluids

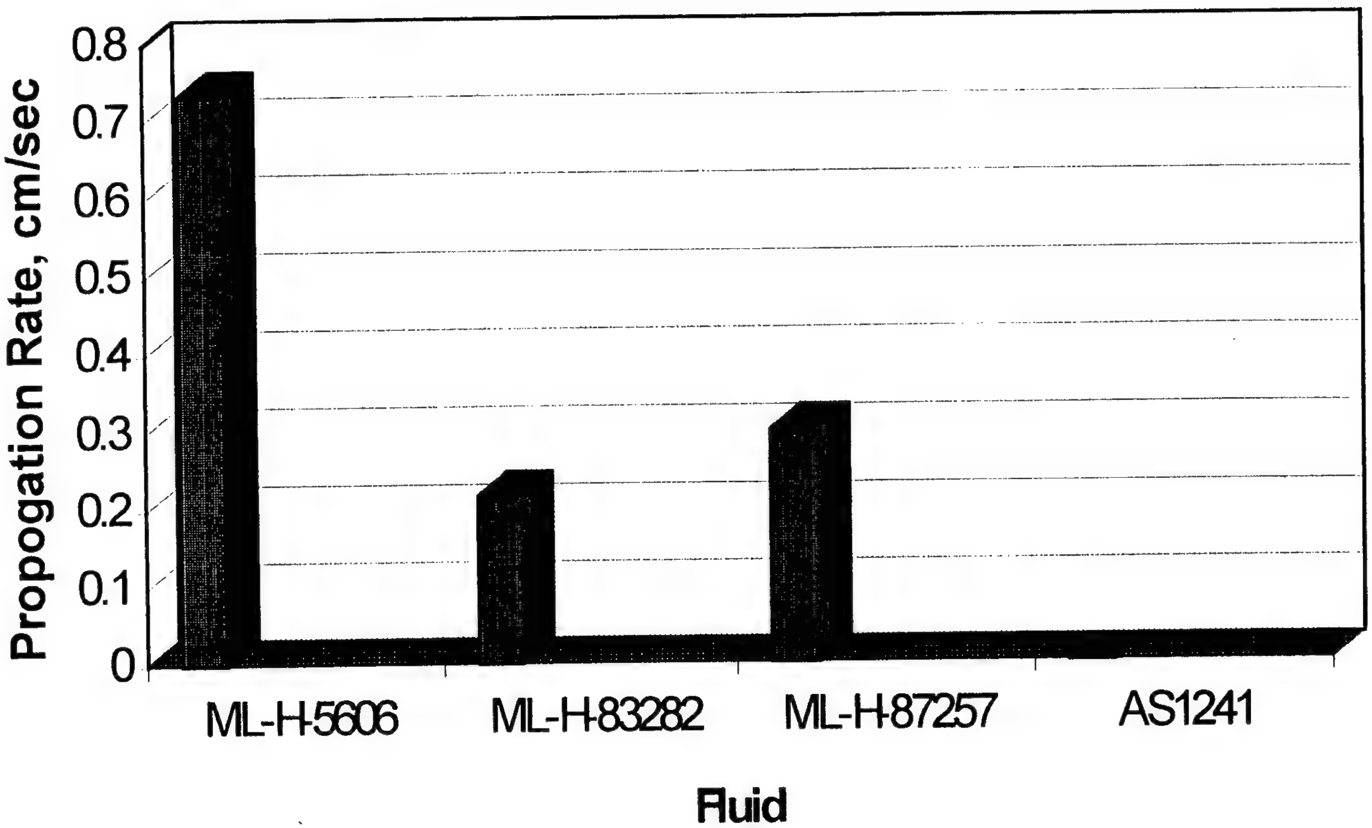



Typical Fire Points of Fire Resistant Hydraulic Fluids
Fire Point, oC
250
200
150
100
50
0
MIL-H-5606
MIL-H-83282
MIL-H-87257
AS1241
Fluid

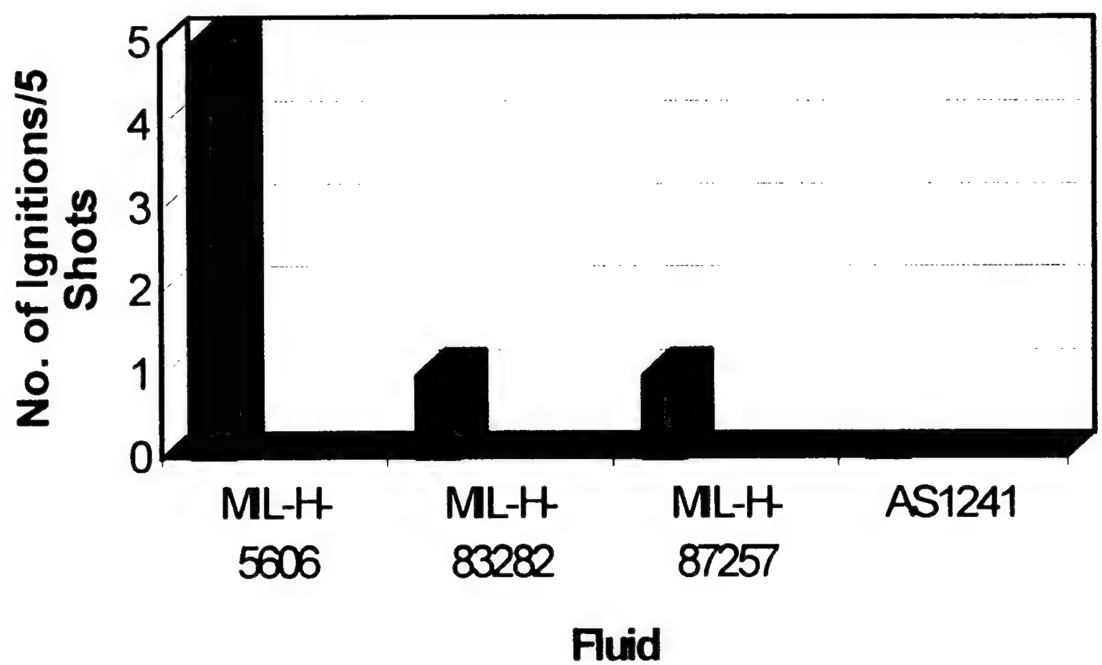
Typical AIT of Fire Resistant Hydraulic Fluids



Typical Flame Propogation Rates of Fire Resistant Hydraulic Fluid



Typical Gunfire Ignition Characteristics of Fire Resistant Hydraulic Fluids



AS1241 - Phosphate ester-based

- Very successful in commercial aircraft
  - Superior fire resistance
  - Lower thermal stability than military needs
  - Early problems with servovalve erosion solved with Type IV fluids
  - Used in military only in "off the shelf" commercial aircraft (C-9, 747ABCP, etc.)

AS1241 - Phosphate ester-based

- Why did the military not convert to AS1241?
  - MIL-H-5606 and AS1241 are incompatible
  - MIL-H-5606 systems are incompatible with AS1241 systems - retrofit prohibitively expensive
  - Logistic problems with two fluid systems
  - Military operations require higher temperature

MIL-PRF-83282

- Polyalphaolefin based synthetic hydrocarbon selected - over 20 candidate base fluids investigated - Specification issued in 1971
- Tri-service evaluation of MIL-H-83282
  - Navy approved 1976
  - Army approved 1977
  - Air Force approved 1980 for most aircraft
- Rust inhibited version, MIL-H-46170 - Army ground vehicle fluid & aircraft bench test and component storage fluid

MIL-PRF-83282

Aircraft Evaluations

MIL-PRF-83282 Aircraft Evaluations

- F-4J Flight Tests (Navy/NATC) (June 71-July 72)
  - 247 Flights - 394.1 Flight Hours (86.7 Cold Soaking at the Tropopause or Above)(Could not repeat OOAMA data)
  - MIL-H-83282 Completely Satisfactory
- F-4D Flight Test (AFLL/OOAMA) - Two Flights 4 Feb 72
  - Outside Air Temperature -85°F
  - Stiff Controls
  - Roll Oscillations of $\pm$ 5° in Autopilot Mode
  - Two Additional Flights at Lower Altitudes - No Problems

MIL-PRF-83282 Aircraft Evaluations, Cont'd

Army Helicopter Tests - Completely Satisfactory Performance

- AH-16 - 1500 Flight Hours
- UH-1M - 1500 Flight Hours
- CH-47 - 1500 Flight Hours & Climatic Hanger Testing Down to -65°F

- F-4B Service Test (101st Marine SQN) (Jan-May 73)
  - High Altitude Cold Soak Missions
  - Cross - Country
  - In-Flight Re-fueling
  - Tail Hook Arrestments

Pilots Could Not Determine Any Difference Between Operational Characteristics of A/C with Use of Either MIL-H-5606 or MIL-H-83282 - Reported Reduced Maintenance

MIL-PRF-83282 Aircraft Evaluations, Cont'd

- A-10 Prototype Qualified on MIL-H-83282 (Except Cold Hangar Tests
- C-130 Alaskan Tests (AF) - (Winter 1980)
    - MIL-H-83282 Acceptable Performance
- NASA Space Shuttle Qualified and Operated on MIL-H-83282

MIL-PRF-83282 (con't)

- Compatibility and interchangability with MIL-H-5606 demonstrated. Conversion by:
  - Attrition - Quit using MIL-H-5606, start using MIL-PRF-83282. Best and less expensive method
  - Drain-and-fill - Fastest fire protection
- Extent of conversion monitored in Air Force aircraft
  - ~ 1 year to reach 95% MIL-PRF-83282

MIL-PRF-83282 (con't)

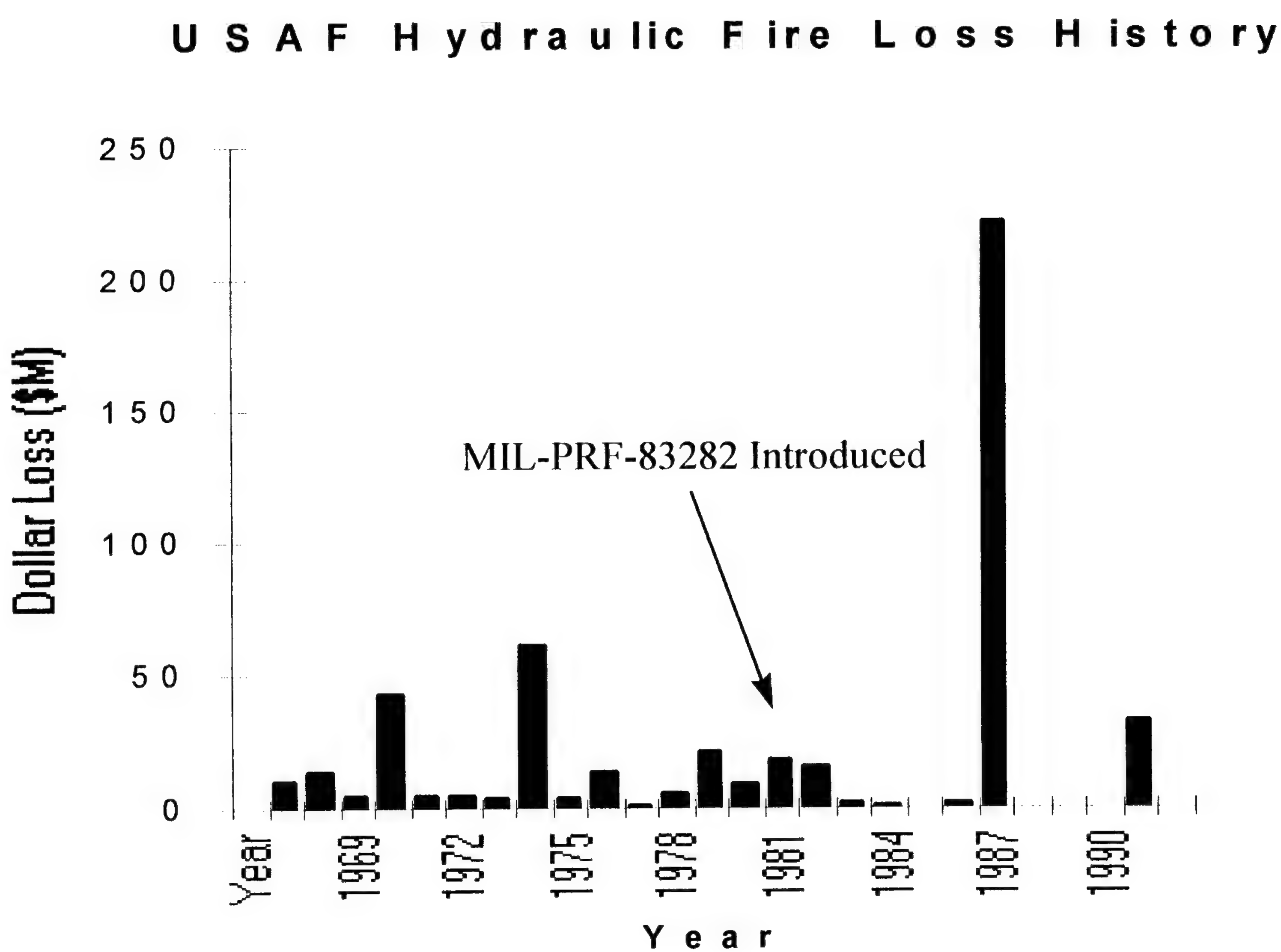
DoD Conversion

- **1976 - Navy Directed Conversion to MIL-H-83282**
  - **50% of Aircraft - Drain and Fill to 95%**
  - **50% of Aircraft - Top Off (Attrition)**
- **1977 - Army Directed Conversion to MIL-H-83282 - All by Attrition**
- **1980 - Air Force Directed Conversion by Attrition**
  - **A-10 Immediately**
  - **Balance of Fleet in 1982**

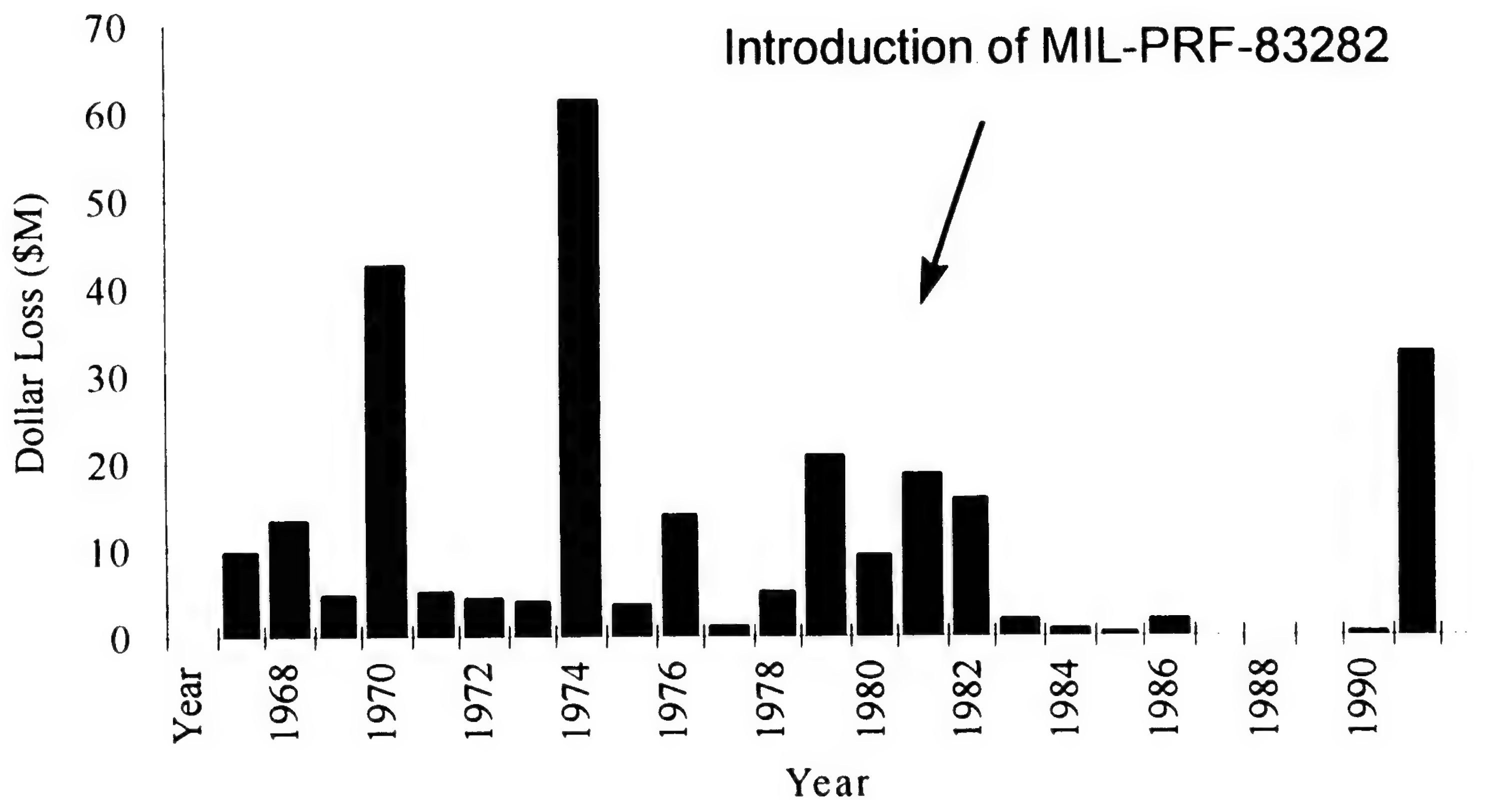
MIL-PRF-83282 (con't)

MIL-PRF-83282 Conversion Successful

- **Many different A/C converted by attrition**
- **No major problems**
  - **Some high time aircraft required filter change shortly after conversion - then back to normal**
- **Significant Reduction in Hydraulic Fire *<u>Damage</u>***


USAF Hydraulic Fire Loss History
250
200
150
100
50
0
Dollar Loss ($M)
MIL-PRF-83282 Introduced
Year
1969
1972
1975
1978
1981
1984
1987
1990
Year

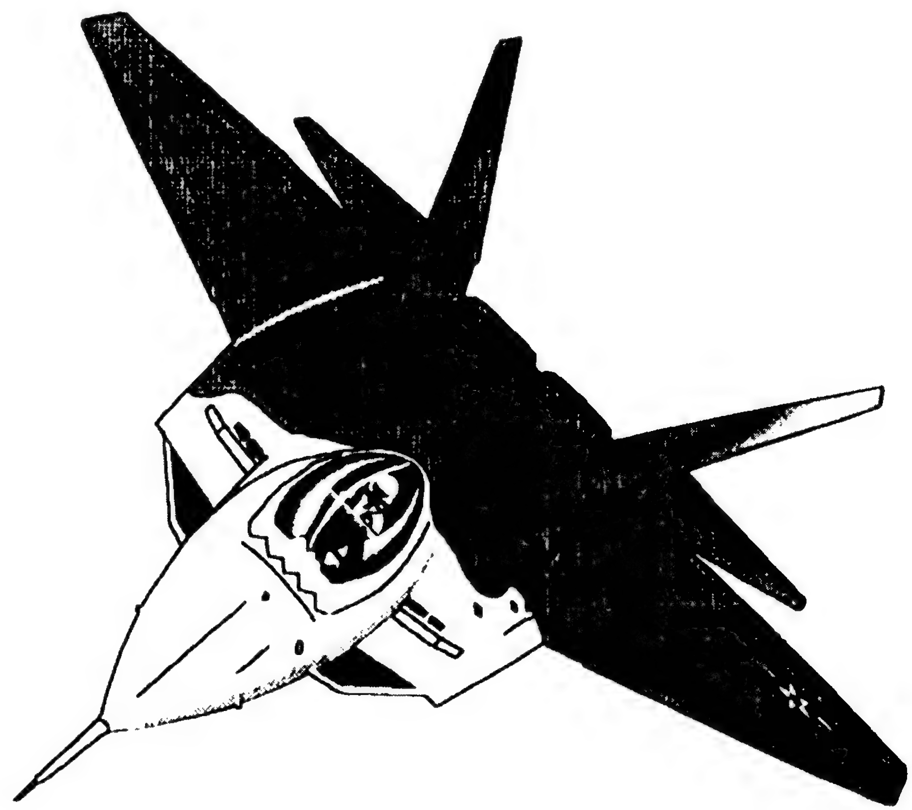
USAF Hydraulic Fluid Fire Loss History
(Excluding 1987)



MIL-PRF-83282 (con't)

- MIL-PRF-83282 has higher viscosity at low temperature than MIL-H-5606 - concern about alert requirements
  - SAC aircraft were not converted to MIL-PRF-83282
  - Air Force required a ***fire resistant*** "drain-and-fill" replacement for MIL-H-5606 with ***equivalent low temperature viscosity***

MIL-PRF- 87257 DEVELOPMENT



Lois Gschwender
U.S. Air Force Research Laboratory
Wright-Patterson Air Force Base, Ohio, USA

OUTLINE

- Requirements
- Base Fluid Approaches
- Property Comparison Trade-Off
- Outcome - Selection of PAO Dimer/Trimer Blend

MIL-PRF-87257 Development

- MIL-PRF-83282 has higher viscosity at low temperature than MIL-H-5606 - concern over alert capability
  - Strategic Air Command aircraft not converted to MIL-H-83282
  - Air Force required a ***fire resistant, drain-and-fill*** replacement for MIL-H-5606 with ***equivalent low temperature viscosity***

MIL-PRF-87257 Development

Initially called *"low temperature MIL-H-83282"* program

Objective - To develop a -54 to 135°C, shear stable, fire-resistant Air Force hydraulic fluid conforming to TN-ASD-AFWAL-1108-78-16

- Kinematic viscosity (cSt)
  - -54°C 2500 (max)
  - 99°C 3.5 (min)

MIL-PRF-87257 Development

More target requirements

- Flash point - 170°C (min)
- Shear stable to 8000 psi at 135°C
- Improved lubricity over MIL-H-5606
- Lower volatility than MIL-H-5606

Hydraulic Fluid Components

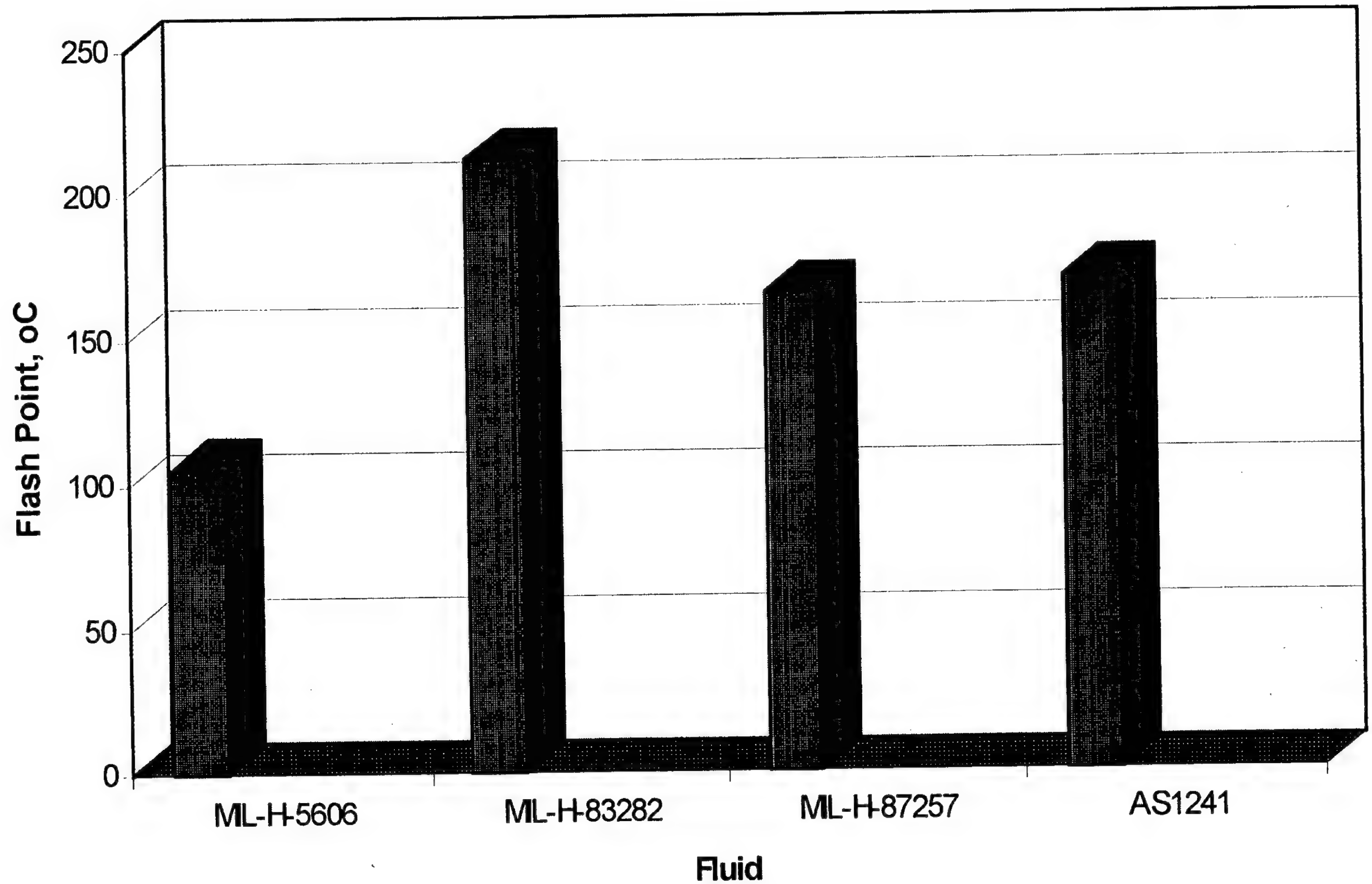
- Base fluid
- Additives
  - Rubber swell (naturally in MIL-H-5606, added to synthetics)
  - Viscosity index improver (if needed)
  - Antioxidant
  - Antiwear
  - Metal deactivator (if needed)
  - Antifoam
  - Red dye

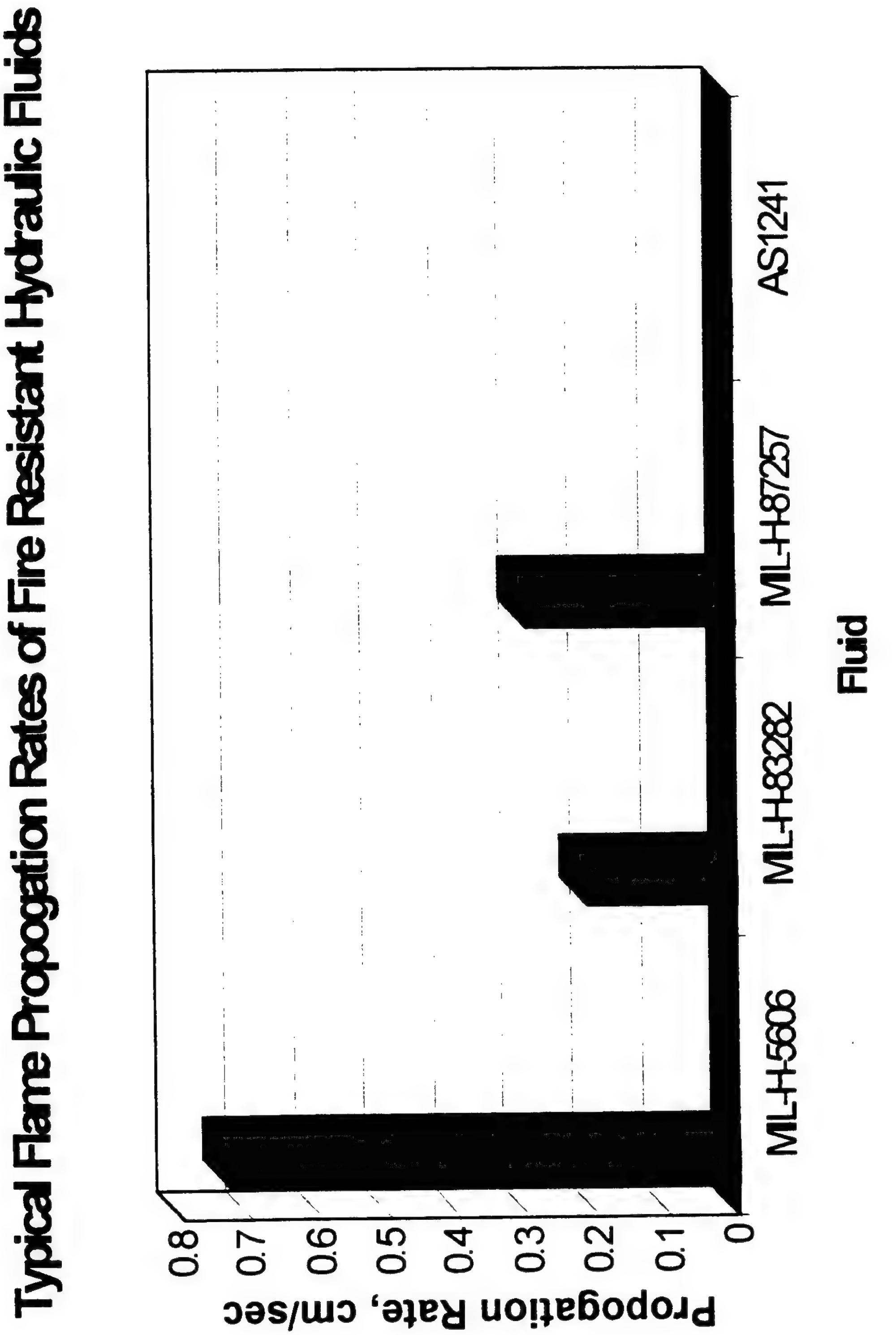
MIL-PRF-87257 Development

Approaches for base fluid

- Silahydrocarbon
- Polyalphaolefin dimer + viscosity index improver
- Polyalphaolefin dimer / trimer blend

Typical Flash Points of Fire Resistant Hydraulic Fluids




Typical Flame Propogation Rates of Fire Resistant Hydraulic Fluids
Propogation Rate, cm/sec
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
ML-H-5606
ML-H-83282
ML-H-87257
AS1241
Fluid

MIL-PRF-87257 Development

PROPERTIES	FLUIDS				
	MIL-H-5606	MIL-PRF-83282	SiHC	PAO VI	PAO dimer/ trimer
Kinematic viscosity, cSt					
-54°C	2100	10,000	2410	2160	2480
100°C	5.1	3.5	2.58	3.53	2.2
Four ball wear, mm	0.98	0.6	0.83	0.62	0.67
Shear stability, %visc.					
loss at 40°C	-14	0	0	-11	0
Flash point, °C (COC)	105	225	227	174	166

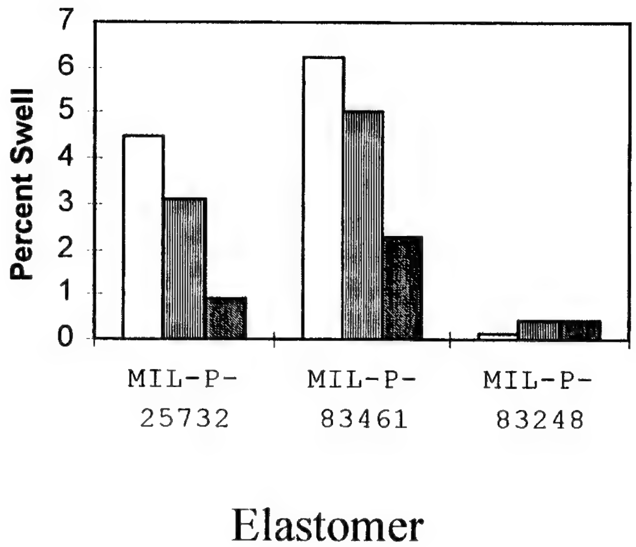
MIL-PRF-87257 Development

Successful elastomeric seal testing

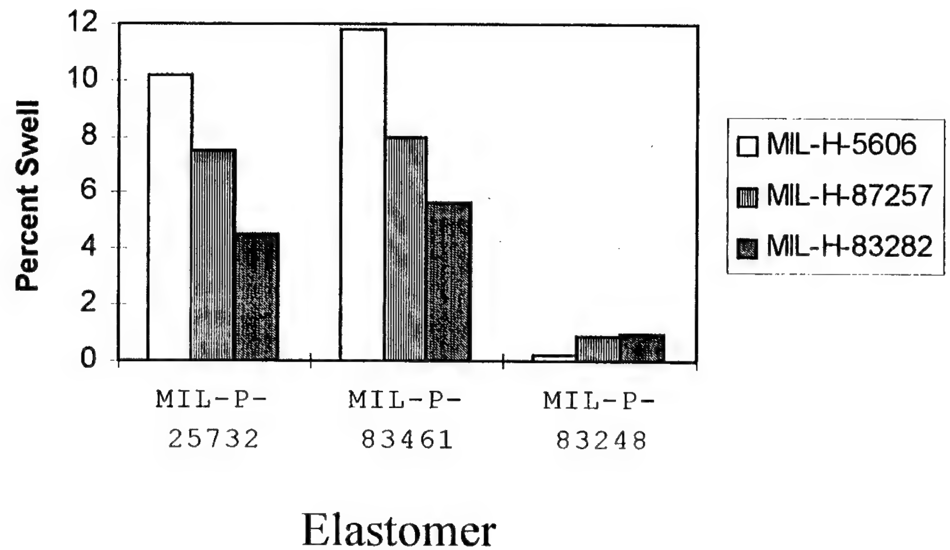
- Static - Also tested MIL-H-5606 and MIL-PRF-83282 as baselines
  - Peroxide and sulfur cured nitrile
  - Fluorocarbon, Viton and Viton GLT
- Dynamic
  - Simulated compression set with MIL-H-5606 and MIL-PRF-83282 at high temperature, then switched to MIL-PRF-87257,- Could not induce leakage at any temperature.

MIL-PRF-87257 Development

Elastomer Compatibility @ 75°F

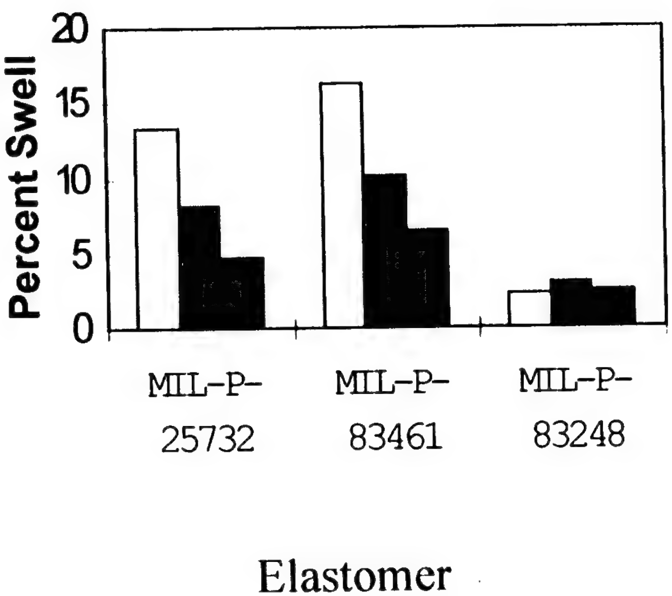


Elastomer Compatibility @ 150°F

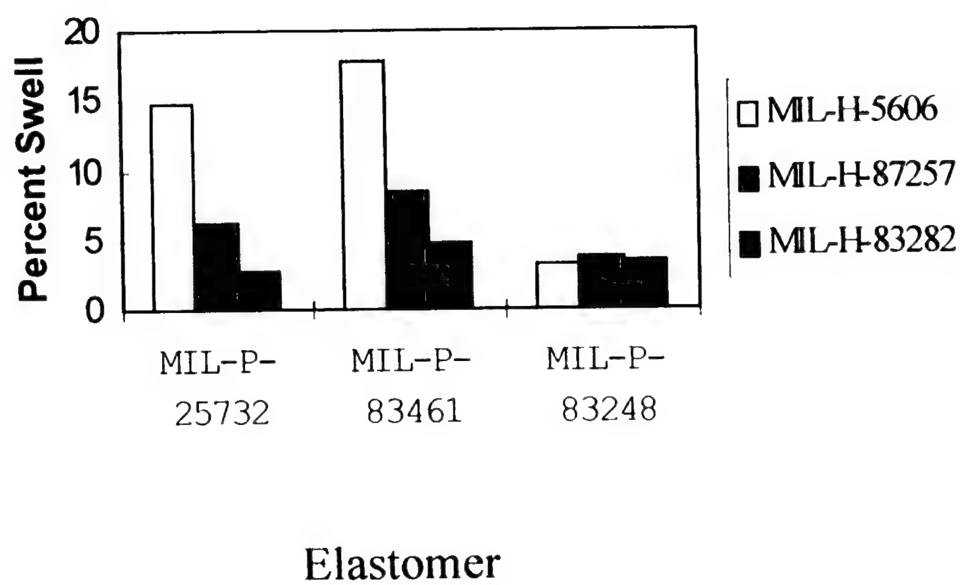


MIL-PRF-87257 Development

Elastomer Compatibility @ 225°F



Elastomer Compatibility @ 275°F



MIL-PRF-87257 Development

Comparison of base fluid properties - overall assessment

	Fire Res	VI	Shear Stability	Commer-cialization	Cost	Tech Risk	Perfor-mance
SiHC	++	++	++	--	--	-	-
PAO VI	+	++	--	++	++	+	+
PAO dimer trimer	+	+	++	++	++	+	++

++ excellent

\+ acceptable

\- some problem

-- significant problem

MIL-PRF-87257 Development

- Outcome - Based on
  - Requirements
  - Property data
  - Pump test results
- PAO dimer / trimer blend emerged as optimum MIL-H-5606 replacement fluid - MIL-H-87257

Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

Shashi Sharma

Materials and Manufacturing Directorate
Air Force Research Laboratory, WPAFB

Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

- Candidate Fluids
- Test Pump
- Test Stand
- Pump Test Results
- Summary

Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

Candidate Fluids

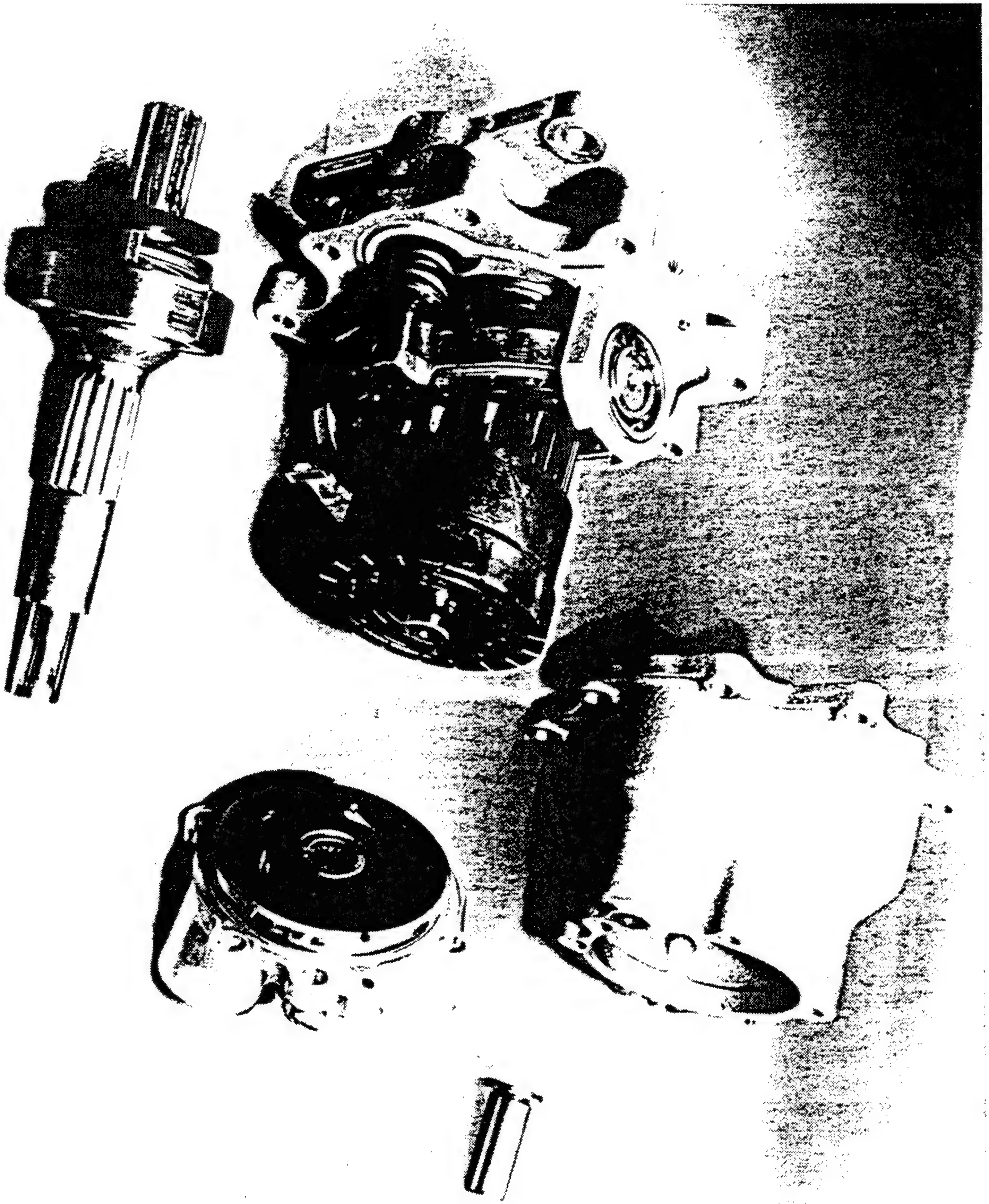
Batch No.	Fluid Description
MLO 81-151	Silahydrocarbon
MLO 85-306	PAO* Dimer + VI Improver + Metal Deactivator
MLO 85-109	PAO Dimer + Trimer
MLO 85-255	PAO Dimer + Trimer
MLO 86-38	*PAO Dimer + Trimer + Metal Deactivator*

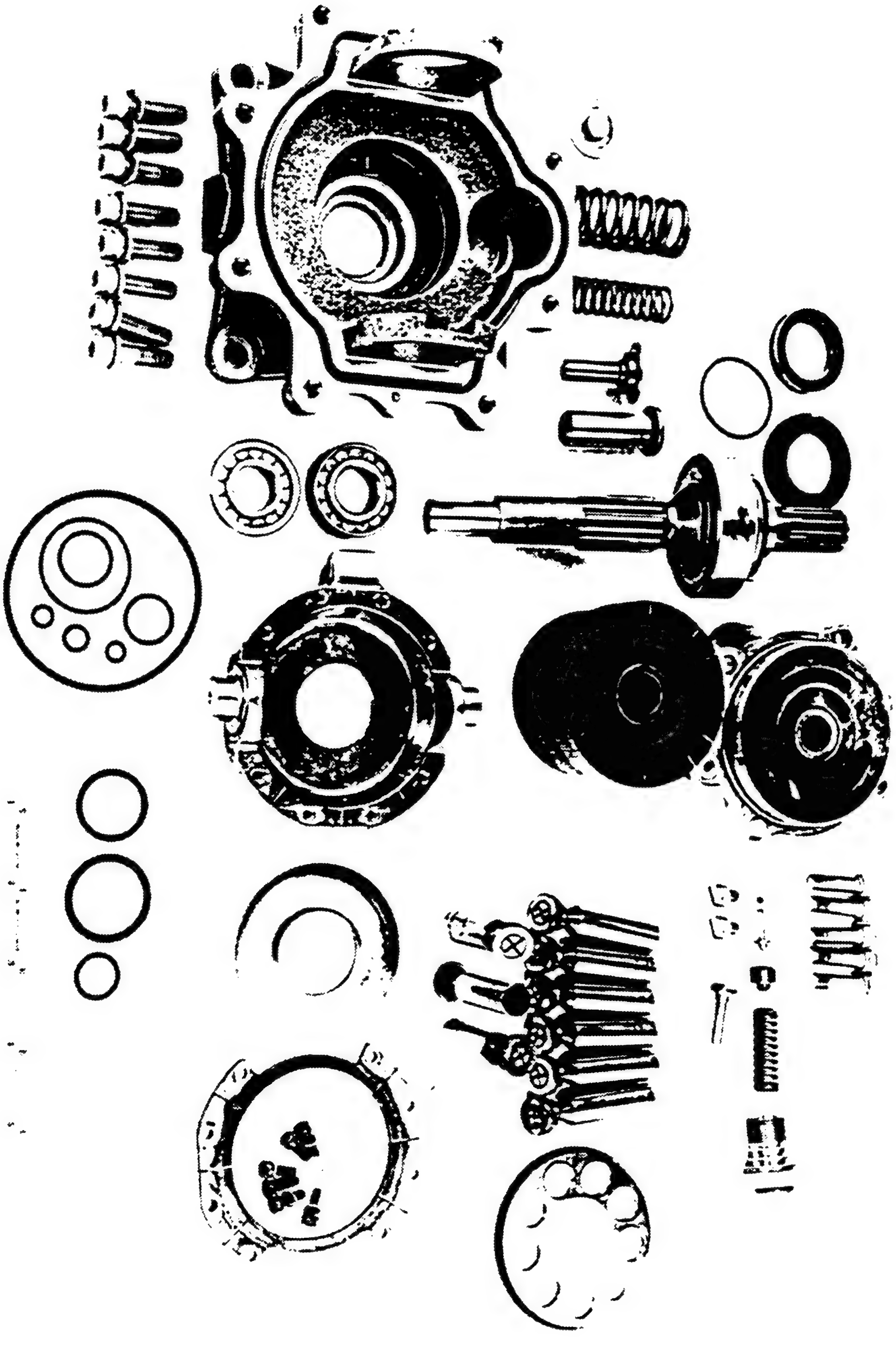
* PAO: Polyalphaolefin

Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

Test Pump

- Vickers Model PV3-075-15
  - Axial Flow Piston Pump
  - 3000 psig Pressure Compensated
  - 40 Horse Power at 7000 rpm
  - 22 gpm Flow Rate at 7000 rpm





Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

Lubrication Regimes

- *Boundary Lubrication*
  - Gross Metal-Metal Contact
  - Lower Entraining Speeds
  - Influenced by the Chemistry of the Lubricant and Material Properties of the Surfaces
  - Anti-Wear Additives and Surface Modifications Help
- *Fluid Film Lubrication*
  - Film Thickness Large Compared to Surface Roughness
  - No (or rare) Metal-Metal Contacts
  - Film Thickness and Power Losses Affected By
    - » Viscosity of the Lubricant
    - » Pressure-Viscosity Effects

Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

- *Surfaces Under Boundary Lubrication*
    - » Actuator Piston
    - » Shaft and Cylinder Block Splines
    - » Pintle Bearings
  - Following Rotating/Sliding Interfaces at Slower Speeds
    - » Cylinder Block and Valve Plate Faces
    - » Piston Shoe Faces and Piston
    - » Pistons and Cylinder Bores
    - » Hold Down Plate and Bearing Plate
    - » Main Thrust Ball Bearing and Needle Bearing

- *Surfaces Under Fluid Film Lubrication*
  - Following Rotating/Sliding Interfaces at Higher Speeds
    - » Piston Shoe Ball Joints
    - » Cylinder Block and Valve Plate Faces
    - » Piston Shoe Faces and Piston
    - » Pistons and Cylinder Bores
    - » Hold Down Plate and Bearing Plate
    - » Main Thrust Ball Bearing and Needle Bearing

Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

Test Stand

- All Stainless Steel and Materials Compatible with CTFE
- Capable of 8000 psig and 350°F
- Test Loop Volume ~ 1 Gallon
- Instrumented to Operate Unattended

AUGUST, 1993

lubrication engineering

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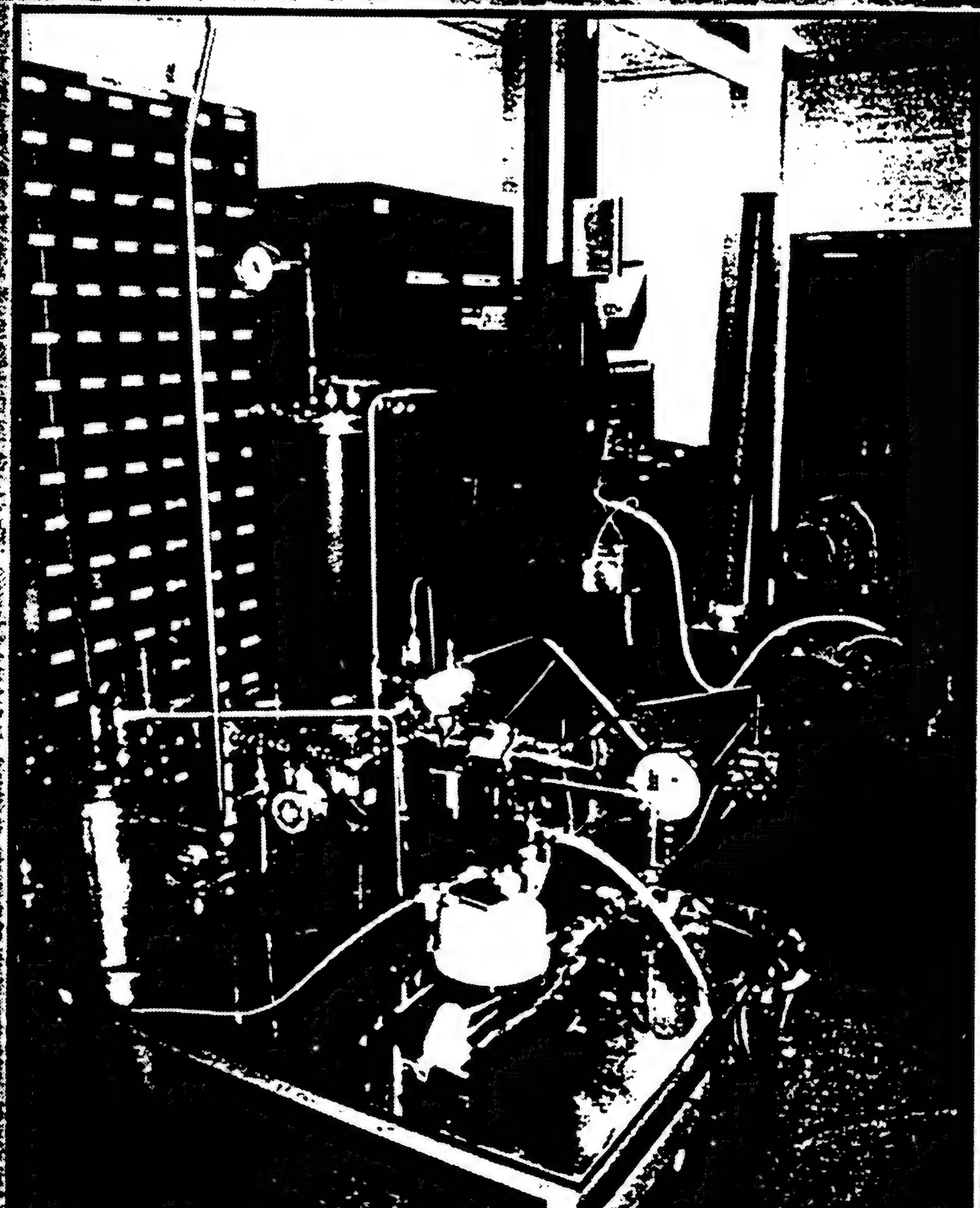
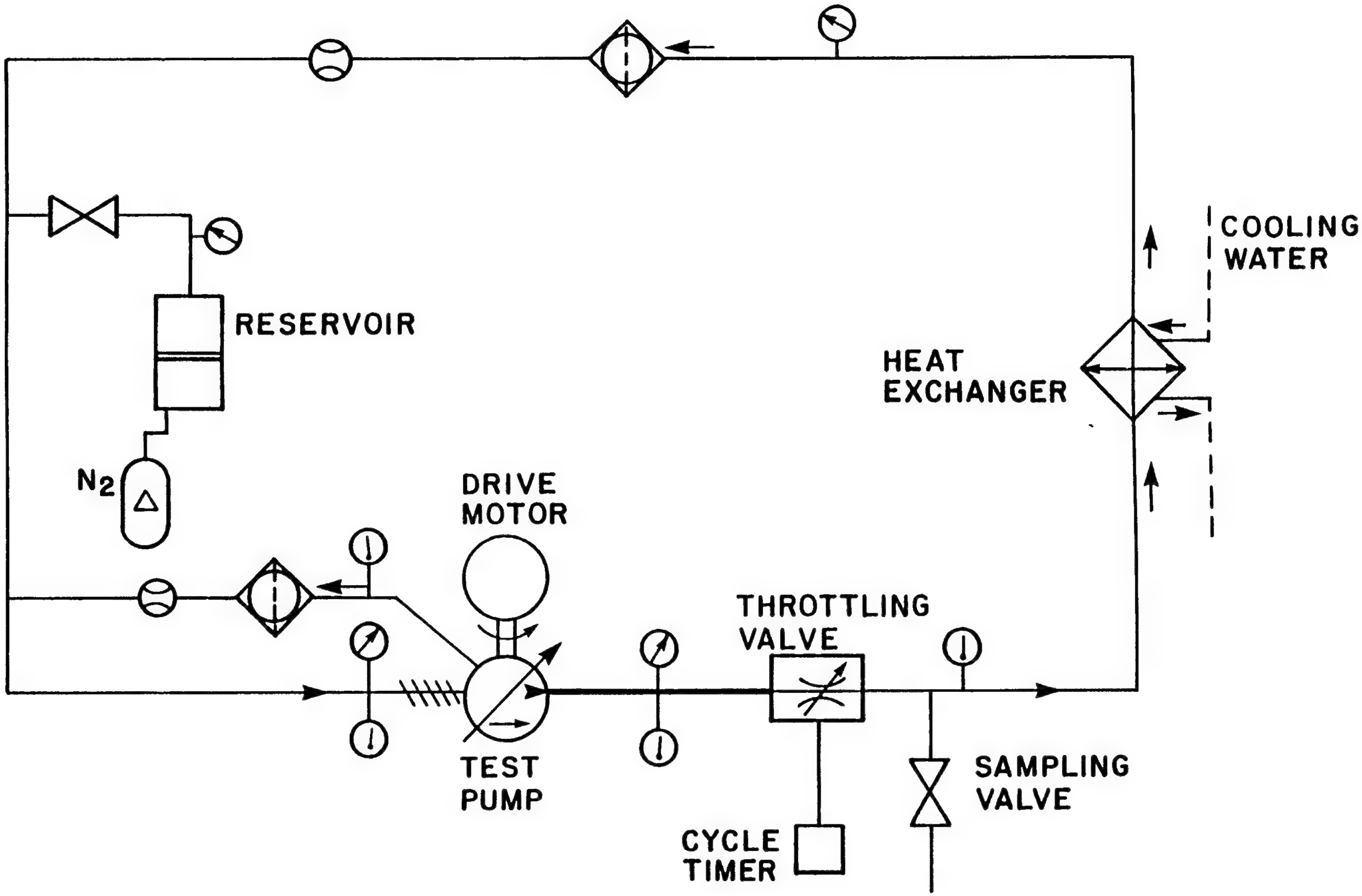



COOLING
WATER
RESERVOIR
HEAT
EXCHANGER
N_2
DRIVE
MOTOR
THROTTLING
VALVE
TEST
PUMP
SAMPLING
VALVE
CYCLE
TIMER

Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

Test Parameters

- Pump Outlet Pressure 3000 psig
- Pump Inlet Pressure 50-60 psig
- Max Fluid Temperature 255°F
- Main Flow Rate:

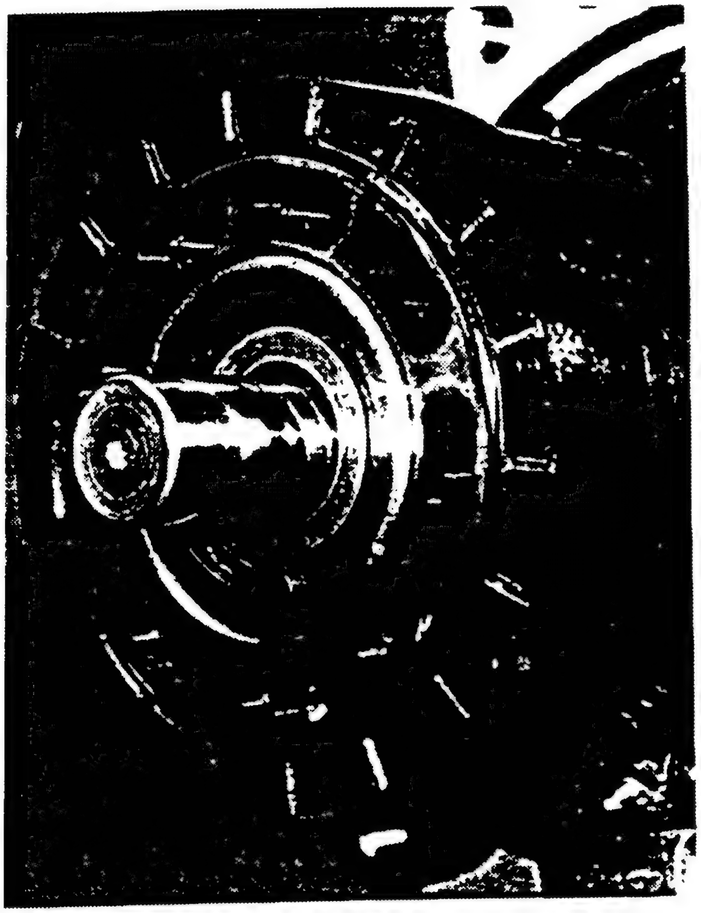
  Cycle Between 12 gpm and
  3 gpm Every Minute
- Pump Speed 5000 rpm

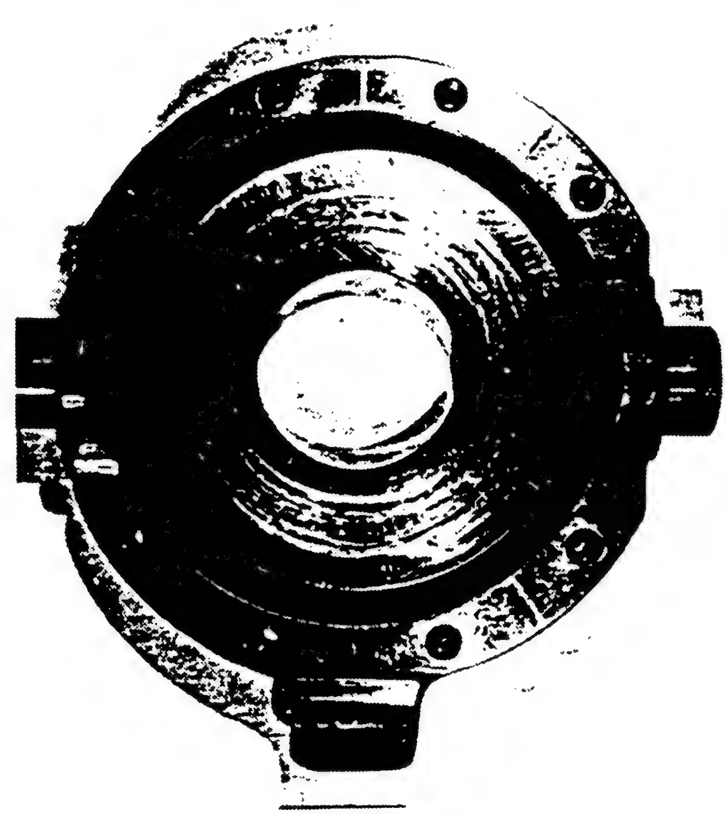
Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

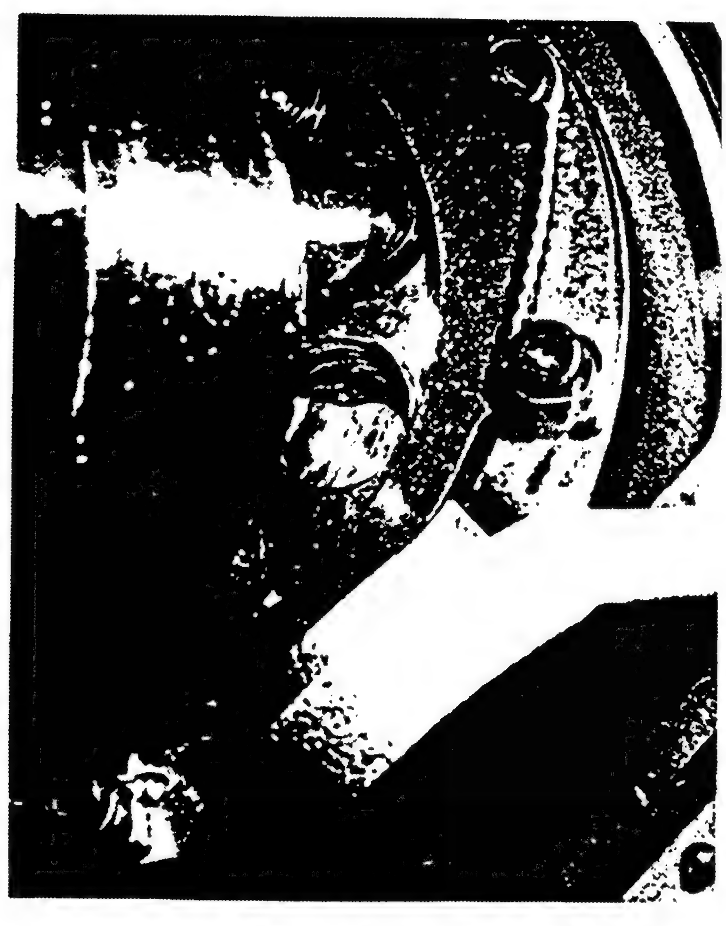
Silahydrocarbon Pump Tests

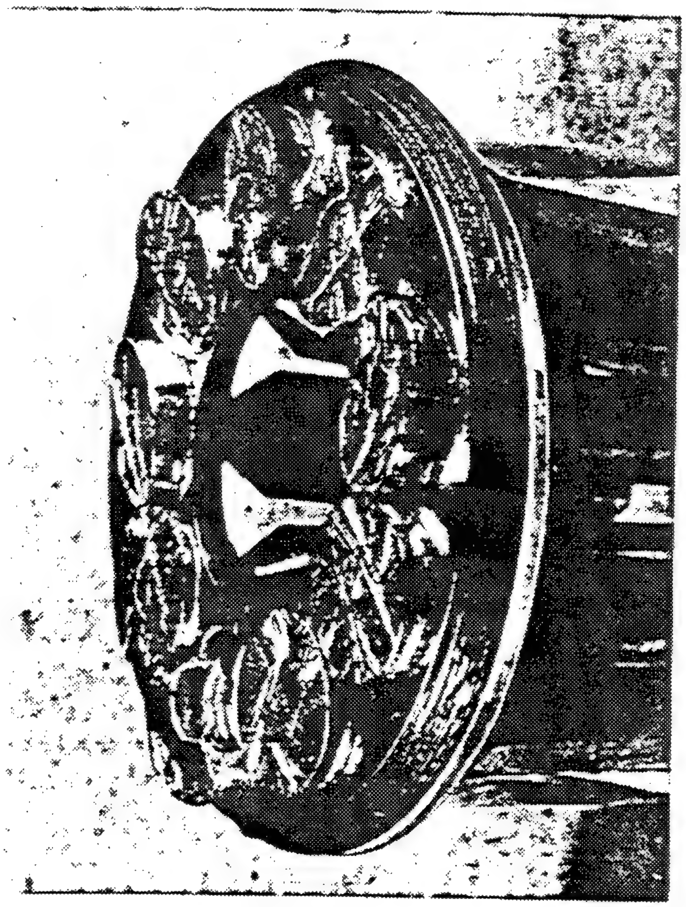
- First Test Failed due to a Piston Break

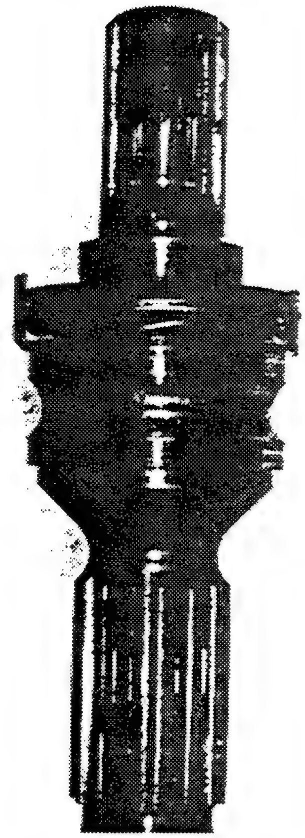
- Second Test Successfully Completed 500 Hours

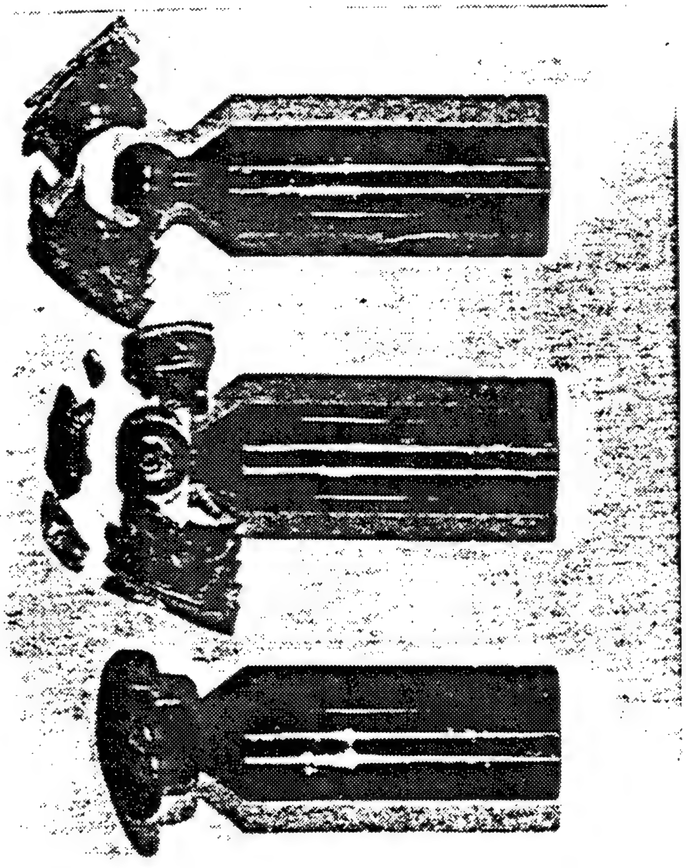


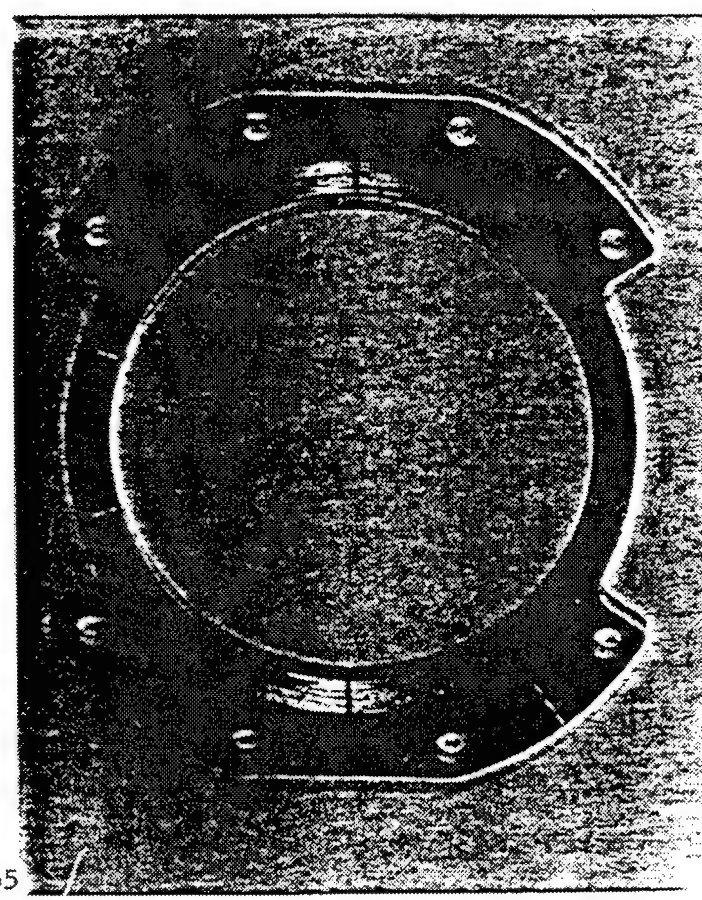


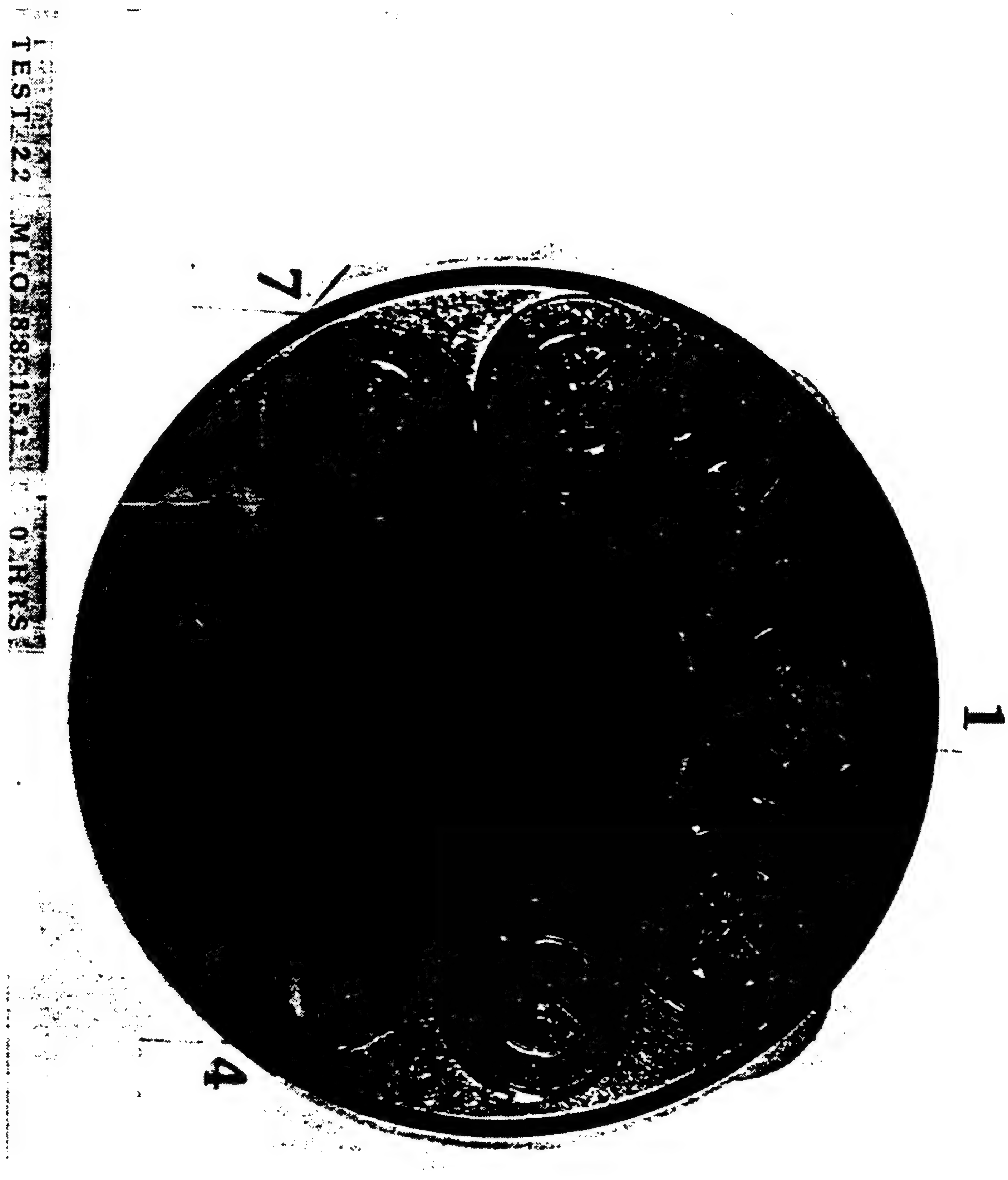


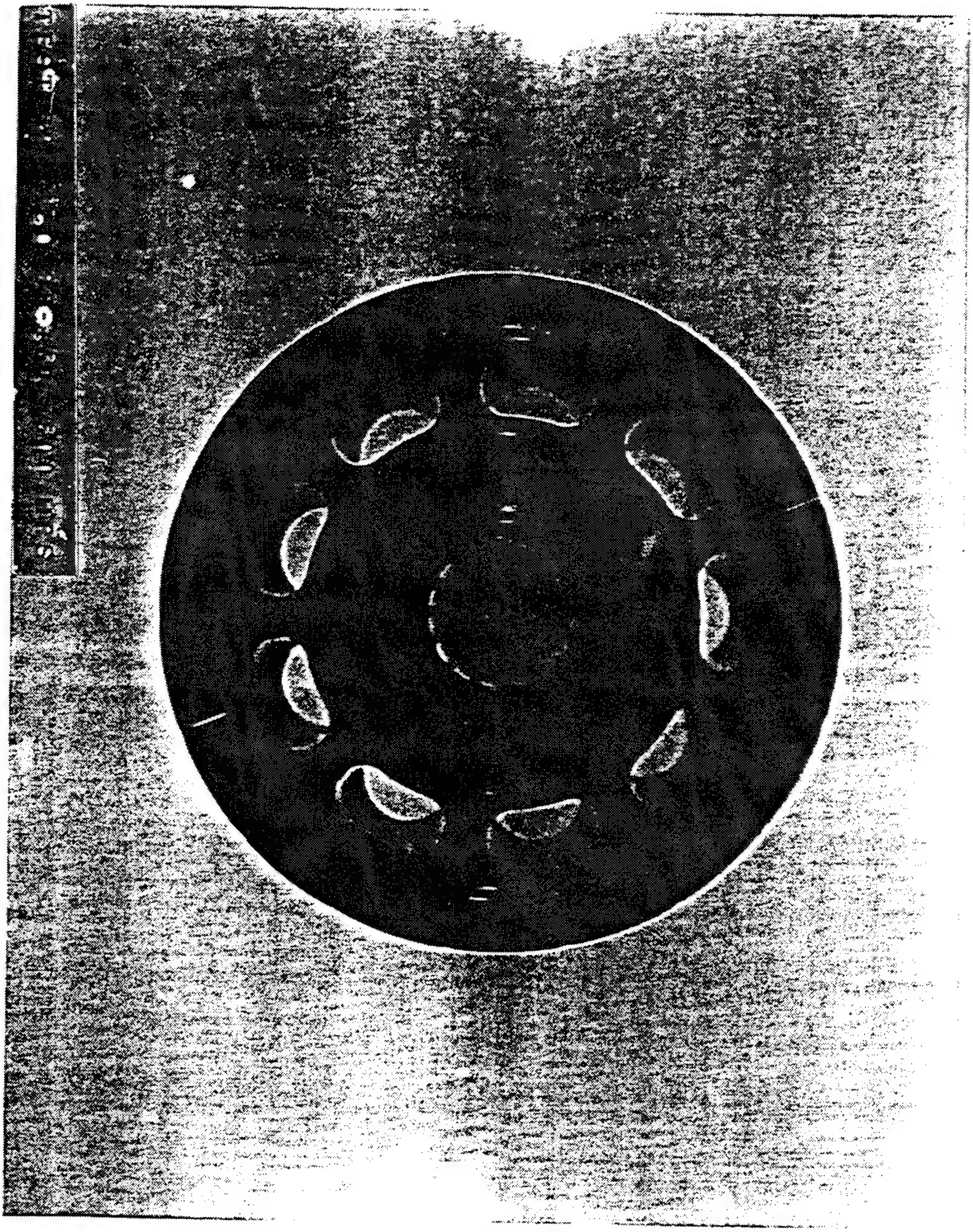


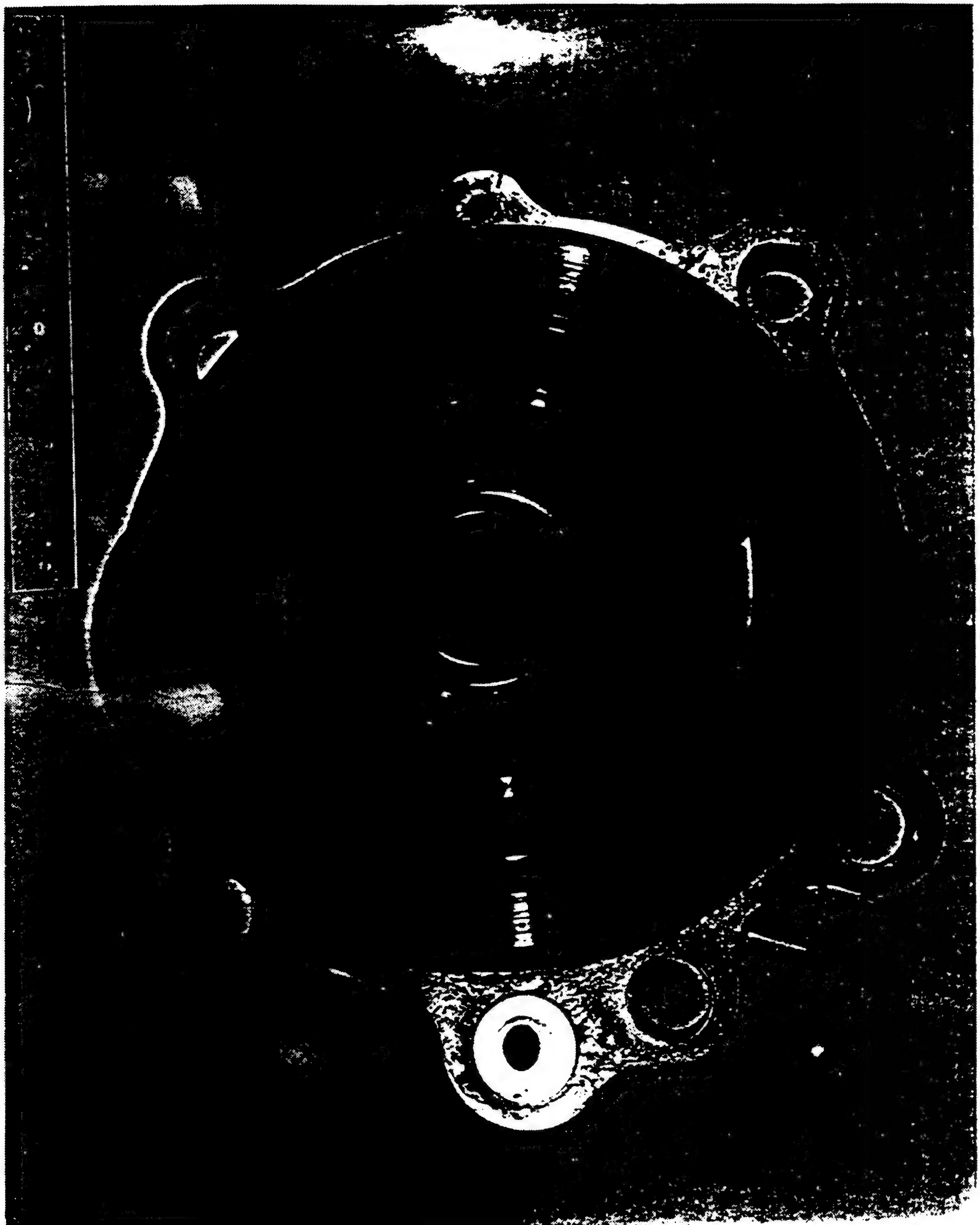







TEST 22 MLO 88-115-1 0 HRS
7
1
4

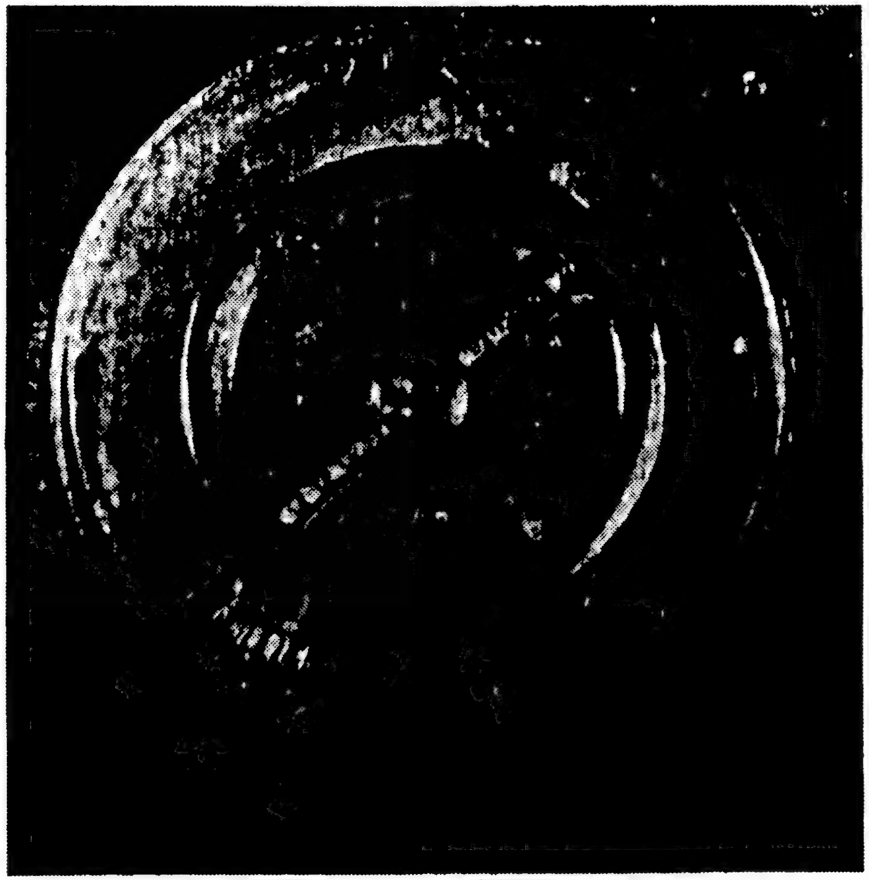




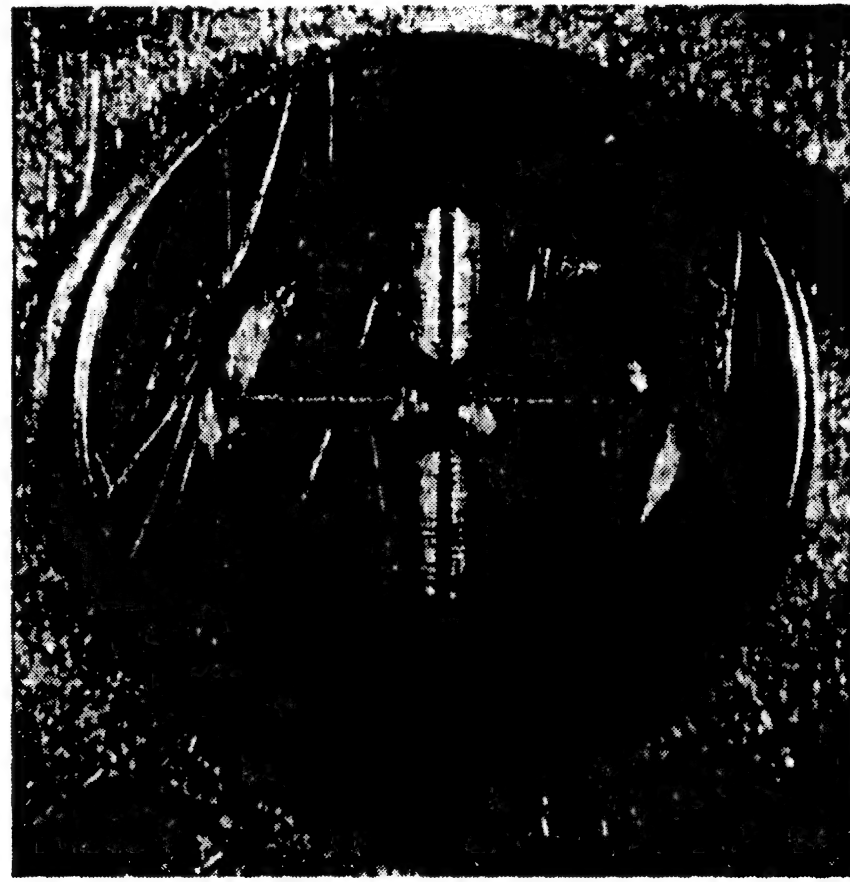
Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

PAO Pump Tests

- All 500 Hour Tests Successful
- Slight Discoloration of Bronze Parts when Test Fluid did not Contain Benzotriazole (Metal Deactivator)
- More Wear Observed on Piston Shoes in Pump Test with VI Improved Fluid

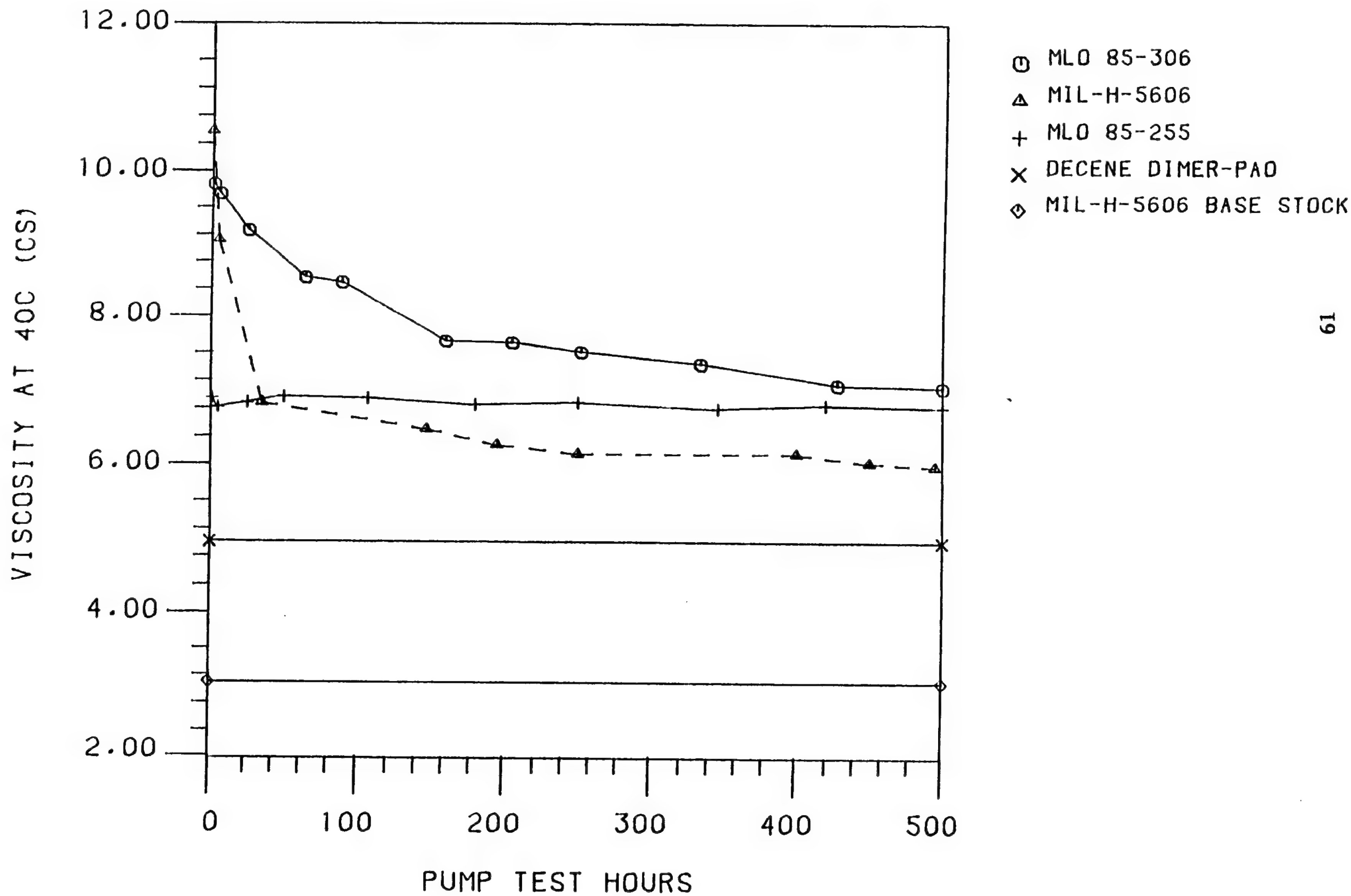


PAO DIMER + VI IMROVER



PAO DIMER + TRIMER

VISCOSITY LOSS IN PUMP TEST



Pump Tests With MIL-PRF-87257 Candidate Hydraulic Fluids

Summary

- All Candidate Fluids Successfully Completed 500 Hour Pump Tests
- Metal Deactivator Eliminated Discoloration of Bronze Parts
- Viscosity of Fluid with VI Improver Decreased During Pump Test
- More Wear Observed on Piston Shoes in Pump Test with VI Improved Fluid
- *PAO Dimer + Trimer + Metal Deactivator Fluid Most Desirable*

MIL-H-87257 TRANSITION

Oklahoma City ALC Conversion Meeting, Groups Represented:

- A/C Systems: KC-135, B-1B, B-52, E-3A
- Air Mobility Command
- Cold hanger test facility
- Rockwell
- Vickers

MIL-H-87257 (con't)

- B-1
  - Validated in PRAM Program
    - » Rockwell - lab component tests and flight simulator
    - » Subcontractors
      - Sterer - nose wheel steering
      - Gull - fluid quantity gauging system
      - Speco - Rotary launcher Drive
      - Vickers - Hydraulic pumps
    - » Follow-up evaluation at Wright Lab in-house pump test
- ***Fluid accepted for B-1 flight test***

MIL-H-87257 (con't)

- C-135
  - Flight test begun Sep 1993 - successfully completed Feb 1994
    - » > 400 hrs flight - no problems with MIL-H-87257
  - Service test begun at McGuire, Malmstromm, McClellan and Eielson AFBs in ~ 40 aircraft
    - » No problems with MIL-H-87257
    - » Maintenance crews very happy with MIL-H-87257

MIL-H-87257 (con't)

- B-1 flight test - began Mar 1995- successfully concluded in Mar 1996
  - No fluid related problems
  - Flight hours - 365.9
  - Main hydraulic pumps were re-inspected and found to be ***better than before*** the test began

MIL-H-87257 (con't)

Conversion Status

- Converted - U2 and EC/KC/RC-135
- Converting - HH-60 and E-3
- In approval process - B-1, B-2 and B-52

MIL-H-87257 (con't)

Other Issues

- Single fluid - logistically desirable
- Use in A/C using MIL-H-83282
  - C-17 - Initial design did not operate satisfactorily at low temperature with MIL-H-83282, MIL-H-87257 performed well in cold hanger tests, but SPO elected to go with hardware modifications
  - Cold hanger tests -

MIL-H-87257 (con't)

- Cold Hanger Tests
  - F-117A " ...to determine if emergency power was available during ground check conditions…compared to…baseline…" Results: Satisfactory checkout at -40°F with no warm-up vs warm-up required with MIL-H-83282. No system degradation at high and low temperatures. Improved performance at low temperatures. (AFFTC-TR-92-03)
  - F-16 Flight controls bits checks improved at low temperature and start temperatures were lower than with MIL-H-83282. (AFFTC-TR-93-22)

TABLE 1.

PHYSIO-CHEMICAL REQUIREMENTS OF AVIATION FLUIDS H-515, H-537 AND H-538

ITEM	PROPERTY	UNIT	LIMITS, H-515		LIMITS, H-537		LIMITS, H-538		TEST METHOD (a)	REMARKS
			MIN	MAX	MIN	MAX	MIN	MAX		
1	Appearance	-	Satisfactory (b)		Satisfactory (b)		Satisfactory (b)		Visual Examination	Clear, homogeneous, free from visible impurities
2	Colour	Lovibond Red Units	20	40	20	40	20	40	IP.17 - Meth A - 1" Cell	The colour of the material may also be defined by comparison with a national standard (c).
3	Solid particles either									
	a. Gravimetric method	mg/100 ml		0		0		0	ASTM D 4898 or MIL-H-5606G paragraph 4.5.6	
	b. Number of particles in micrometers	Nb/100 ml							STANAG 3713 (d)	The figures quoted refer to those obtained using automatic particle counter calibrated with latex spheres.
	>5 up to 15			10,000		10,000		10,000		
	>15 up to 25			1000		1000		1000		
	>25 up to 50			150		150		150		
	>50 up to 100			20		20		20		
	>100 up to 150			5		5		5		
4	Evaporation	wt %		20.0		20.0		20.0	ASTM D 972	H-515: 6 hours @ 71 C
										H-537: 6.5 hours @ 205 C
5	Kinematic Viscosity	cSt								H-538: 6.5 hours @ 135 C
	@ +100 C		4.0	-	3.5		2.0			
	@ +40 C		13.0	-	report		6.7			
	@ -40 C		-	600		2600		550		
	@ -54 C		-	2500		-		2500		

(a) The test methods given in the column are put as a reference (ASTM, FTM, etc.); each national equivalent can be used.

TABLE 1 CONT.
2nd page

ITEM	PROPERTY	UNIT	LIMITS, H-515		LIMITS, H-537		LIMITS, H-538		TEST METHOD	REMARKS
			MIN	MAX	MIN	MAX	MIN	MAX	(a)	
6	Flash point	C	82						ASTM D 93	
					205		170		ASTM D 92	
7	Pour point	C	-	-60	-	-55	-	-60	ASTM D 97	
8	Low temper-ature stability		No gelation, precipitation or separation of solid or liquid phases. Turbidity not greater than standard.						FTM 791	H-515: Method 3459 H-537 and H-538: Method 3458
9	Foaming at 25 C - Foam volume at end of	ml							ASTM D 892	A ring of small bubbles around the edge of the graduate shall be considered satisfactory.
	- 5 min. blowing period			65		65		65		
	- 10 min. settling period.			0		0		0		
10	Total acid number	mg KOH/g		0.2		0.1		0.2	ASTM D 664	
11	Copper corrosion 72 hr at 135 C	-		3		3		3	ASTM D 130	Use the ASTM copper corrosion standards described in para 3.2. Alternate apparatus de-scribed in national speci-fications may be used. (e)
12	Synthetic rubber (NBR-L) swell.	volume %	19.0	30.0	18.0	30.0	19.0	30.0	FTM 791 Method 3603 168 hr at 70 C	Qualification test only.

(b) See Remarks column.

TABLE 1 CONT.
3rd page

ITEM	PROPERTY	UNIT	LIMITS, H-515		LIMITS, H-537		LIMITS, H-538		TEST METHOD	REMARKS
			MIN	MAX	MIN	MAX	MIN	MAX	(a)	
13	Corrosivity/ oxidation stability								ASTM D 4636 135 C, 168 hr	
	a. Weight change of test piece:									
	- Steel			_0.2		_0.2		_0.2		
	- Al alloy			_0.2		_0.2		_0.2		
	- Mg alloy			_0.2		_0.2		_0.2		
	- Cd plated steel			_0.2		_0.2		_0.2		
	- Cu			_0.6		_0.6		_0.6		
	b. Appearance of test pieces		No pitting, etching or visible corrosion under a magnitude of 20 diameters. Cu corrosion not greater than classification 3 (ASTM D 130).							Slight discoloration of Cd will be permitted.
	c. Change in 40 C viscosity from original.	%	-5	20	-10	10	-10	10		
	d. Increase in total acid Nb from original.	mg KOH/g	-	0.2	-	0.2	-	0.2		
	e. Appearance of the fluid after test.		Satisfactory (b)		Satisfactory (b)		Satisfactory (b)			No visible separation of insoluable matter. No gumming.
(c) Compare with standard prepared with one part red dye and 10,000 parts of an oil not darker than ASTM D 1500 #1.										

(d) FTM 791/3009 may be used in lieu of STANAG 3713. Maximum number of particles: 5 to 15: 2500, 16-25: 1000, 26-50: 150, 51-100: 25, over 100: 10.

TABLE 1
4th page

ITEM	PROPERTY	UNIT	LIMITS, H-515		LIMITS, H-537		LIMITS, H-538		TEST METHOD	REMARKS
			MIN	MAX	MIN	MAX	MIN	MAX	(a)	
14	Shear stability								ASTM D 2603	Use 30 ml of fluid (f), test period is 30 minutes.
	Decrease in viscosity from original at 40 C	%	Not greater than the percent decrease in the reference fluid.		N/A		N/A			Viscosity decrease of reference fluid is 15 %.
15	Steel-on-steel wear, average diameter of scar.	mm		1.0		0.65		0.65	ASTM D 4172 Condition B	
16	Storage stability									
	a. Appearance of the fluid after time period.		Item 1 remarks and Item 8 limits.							
	b. Tests to be performed again on the fluid.		Must meet the requirements of Items 3b, 8, 10, 11 and 13.							

(e) A test tube equipped with an air condenser fitted with a cork may be used in lieu of the bomb specified in ASTM D 130. The dimensions are: Test tube: 300X30 mm OD, Condenser tube: 500X7 mm OD.

(f) ASTM Reference Fluid B may be obtained from Rohm and Haas Co., Research Laboratories, Spring House, PA 19477.

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  Fax: (937) 255-2176

BOEING®

B-1B TESTING OF MIL-H-87257

BOEING NORTH AMERICAN

JIMMY L. SCHMIDT

MARCH 17, 1998

BOEING®

HYDRAULIC FLUIDS

MIL-SPEC	COMMON NAME	CHEMISTRY	USED ON
MIL-H-5606	"RED OIL"	MINERAL OIL	F-86, F-100, B-1B & MOST SAC AIRCRAFT
MIL-H-83282	"FIRE RESISTANT HYDRO OIL"	POLYALPHAOLEFIN "PAO" 84% DIMER	X-31, GUNSHIP & MOST TAC AIRCRAFT ALL NAVY AIRCRAFT
MIL-H-87257	"LOW TEMP 83282" "ROYCO 777"	"PAO" 49% DIMER 16.5% TRIMER	PROPOSED FOR B-1B, B-2, TRANSPORTS & MOST SAC AIRCRAFT

ALL THREE FLUIDS ARE:

COMPATIBLE WITH EACH OTHER
COMPATIBLE WITH SAME SEALS
MIXABLE

COMPONENTS TESTED (NA-91-1598)

SCAS ACTUATOR

HORIZONTAL STABILIZER ACTUATOR

SMCS ACTUATOR

FLIGHT CONTROL SIMULATOR (IRON BIRD)

TWO WAY FLOW RESTRICTOR

MAIN HYDRAULIC PUMP

WING SWEEP MOTOR

BRAKE METERING VALVE

NOSE WHEEL STEERING

ROTARY LAUNCHER DRIVE

HYDRAULIC QUANTITY GAUGING SYSTEM

HYDRAULIC PUMP TESTING STATEMENT OF WORK (FOR VICKERS

1. Vickers, Inc. to obtain four hydraulic pumps (P/N) form Air Force inventory.

2. Record serial numbers of all four pumps.

3. Perform abbreviated acceptance test per acceptance test procedure TP 7337 using MIL-H-5606 or MIL-H-6083 as the test fluid. Only the following tests will be performed.

   3.5.1.1 Record zero flow pressure.

   3.5.1.3 Record case drain flow.

   3.5.1.4 Record flow rate at full flow.

   3.5.2 Record x-y plot.

4. Disassemble all four pumps. Visually inspect for service suitability and repair as necessary.

DETAILS DIMENSIONS AND

5. Inspect rotating group with special piston/bore chart noting piston ~~to~~ bore clearanceS

6. Visually examine all parts and record condition and photograph as necessary. Rockwell Engineering to participate.

7. Assemble all four pumps.

8. Acceptance test all four pumps per acceptance test procedure ATP 7334.

9. Deliver all four pumps per Rockwell instructions.

10. Air Force to return all four pumps for revaluation after concluding flight testing.

11. Repeat abbreviated acceptance test per acceptance test procedure TP 7337 using MIL-H-5606 or MIL-H-6083 as the test fluid. Only the following tests will be performed.

   3.5.1.1 Record zero flow pressure.

   3.5.1.3 Record case drain flow.

   3.5.1.4 Record flow rate at full flow.

   3.5.2 Record x-y plot.

12. Disassemble all four pumps and compare components with photographs previously taken.

DIMENSIONS AND

13. Reinspect rotating group with special piston/bore chart noting piston ~~to~~ bore clearanceS and compare with pervious inspection.

38164

(#1)

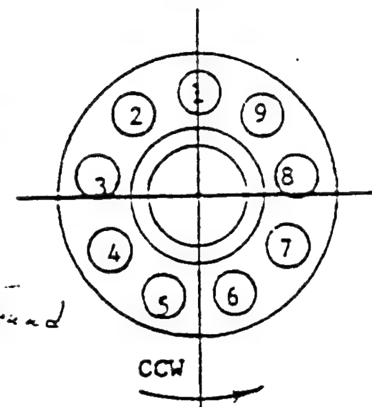
SPECIAL PISTON/BORE CHART

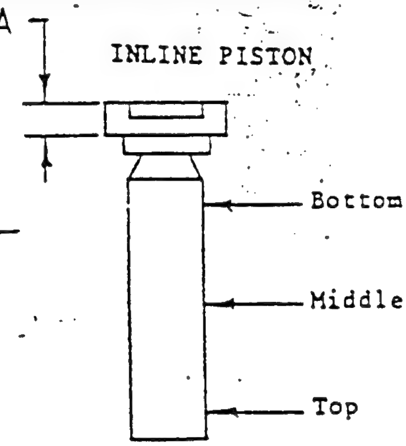
DATA SHEET NO. ______ SERIAL NO. MX438470 MODEL NO. PV3-300-7B

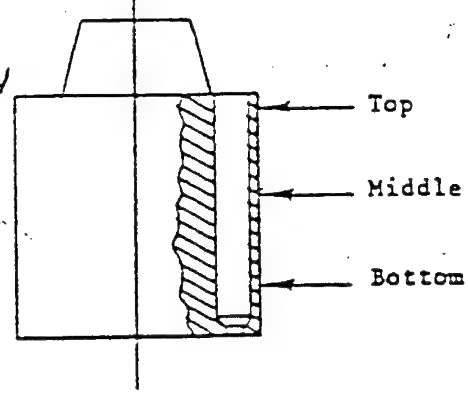
[TE]STED BY: ______ PREPARED BY: ______ PREVIOUS TEST: ______

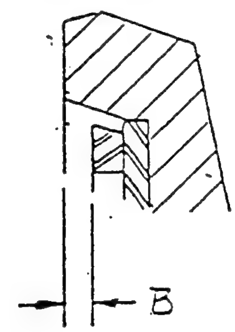
CYL. BLOCK BORES

NO.	TOP	MIDDLE	BOTTOM	
1	.71365	.71370	.71380	
2	.71370	.71380	.71380 to .71450	o/Round
3	.71370	.71370	.71380	
4	.71370	.71365	.71385 to .71430	o/Round
5	.71365	.71370	.71380 to .71375	o/Round
6	.71375	.71375	to .71445	
7	.71370	.71370	.71380	
8	.71370	.71380	.71375 to .71415	o/Round
9	.71370	.71375	.71380	









*CAVICATION EVIDENCE

PISTON-INCHES

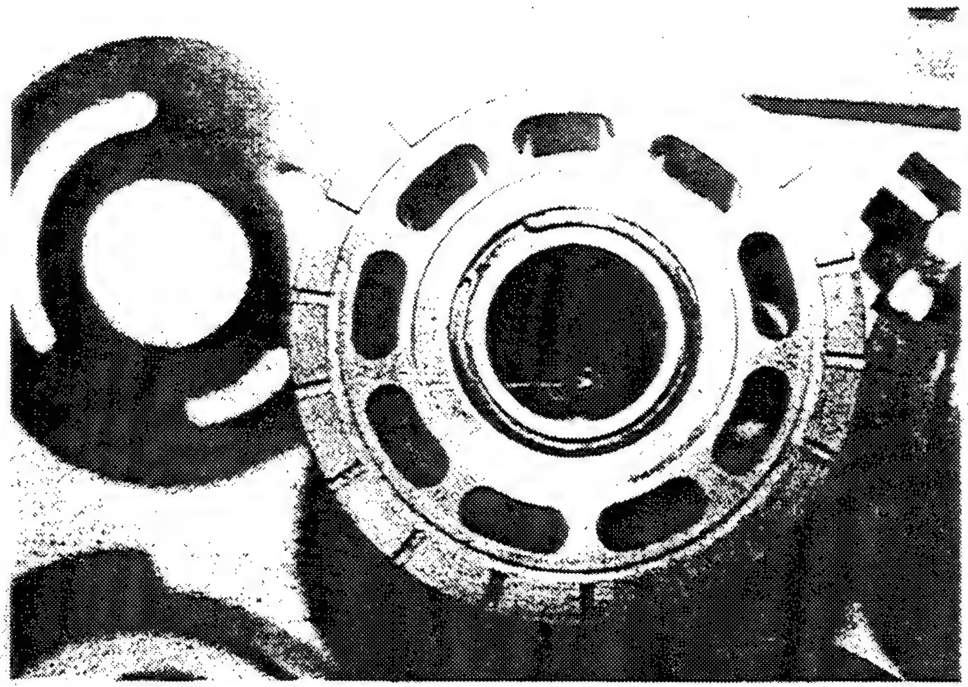
NO.	TOP	MIDDLE	BOTTOM
1	.71210	.71205	.71205
2	.71210	.71205	.71205
3	.71205	.71205	.71205
4	.71210	.71205	.71205
5	.71210	.71210	.71205
6	.71215	.71215	.71215
7	.71215	.71215	.71210
8	.71205	.71205	.71205
9	.71210	.71205	.71205

	NO.	MAX./MIN. PISTON TO BORE CLEARANCE	PISTON TO SHOE END PLAY	DIA. NO. "A"	SHOE RUNNING CLEARANCE DIM No "B"	
	1	.00155 / .00175	.0016	.2518	Min:	.0038
	2	.00160 / .00245	.0014	.2517	Max	.0044
	3	.00165 / .00175	.0010	.2518		
*	4	.00155 / .00225	.0018	.2512		
*	5	.00155 / .00175	.0013	.2517		
	6	.00160 / .00230	.0017	.2517		
	7	.00155 / .00170	.0012	.2518		
	8	.00165 / .00210	.0013	.2518		
	9	.00160 / .00175	.0015	.2516		

S/N MX 438470B, PUMP #1
Photos dated 5 January 1995

PISTON AND SHOE ASSEMBLY

S/N MX 403349, PUMP #2.
Photos dated 15 May 1996.



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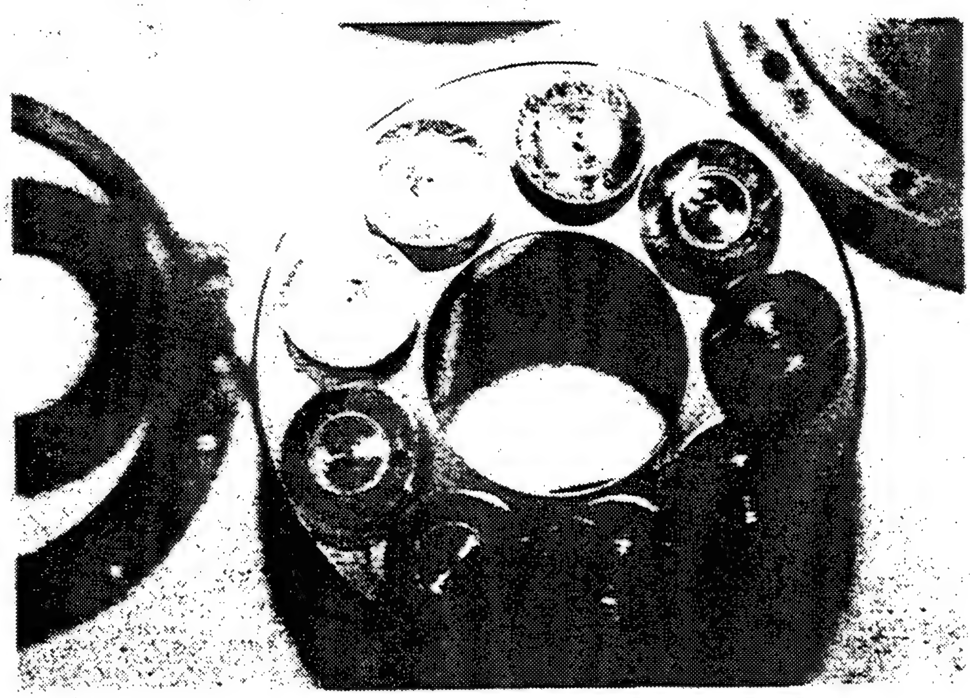
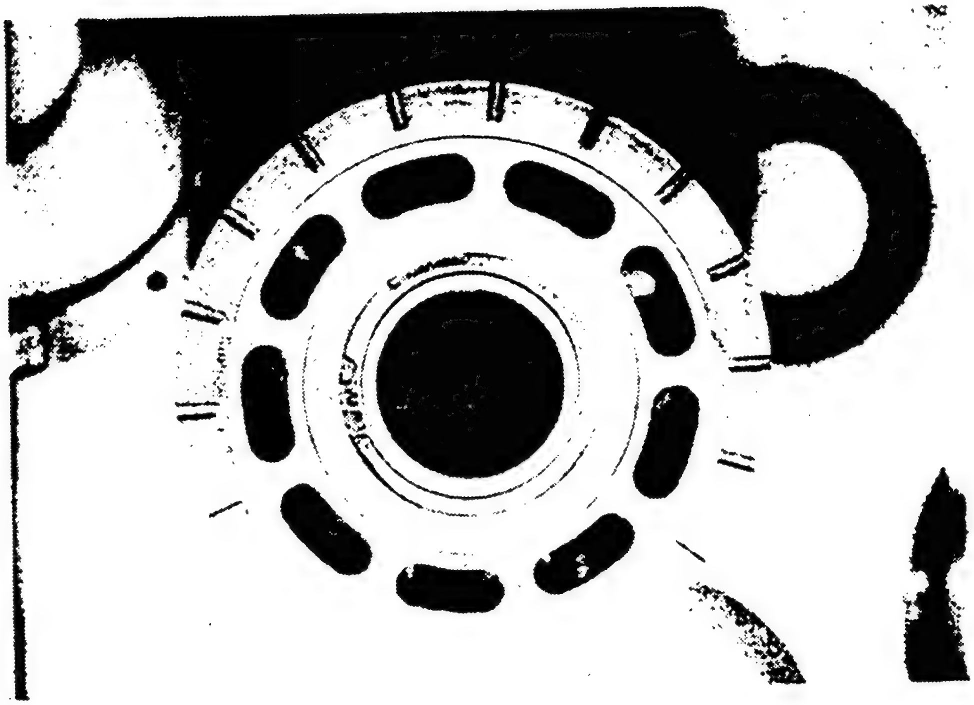


PISTON AND SHOE ASSEMBLY

S/N MX 441537B, PUMP #3
Photos dated 15 May 1996



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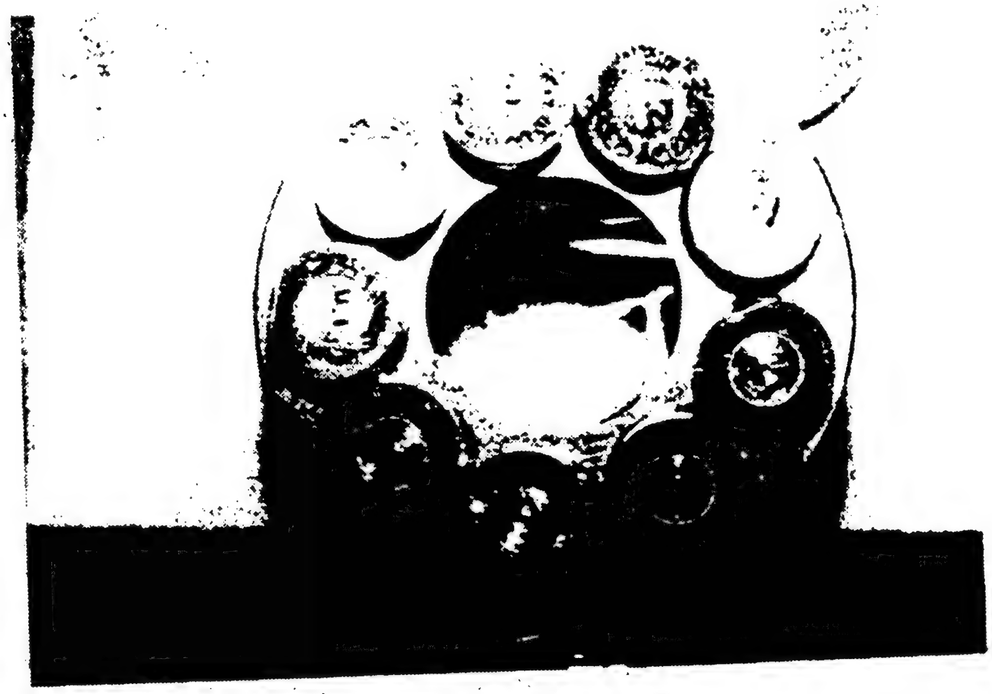
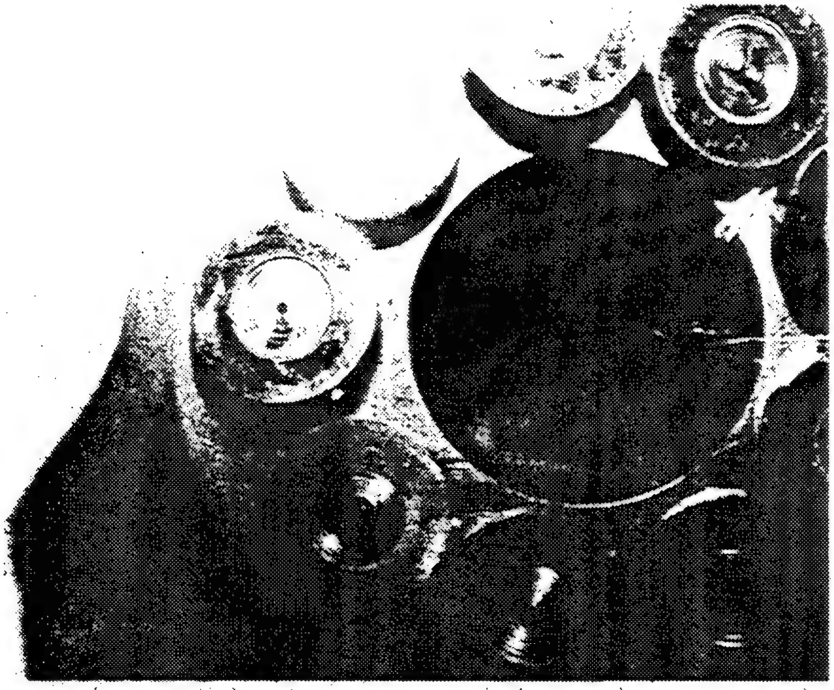
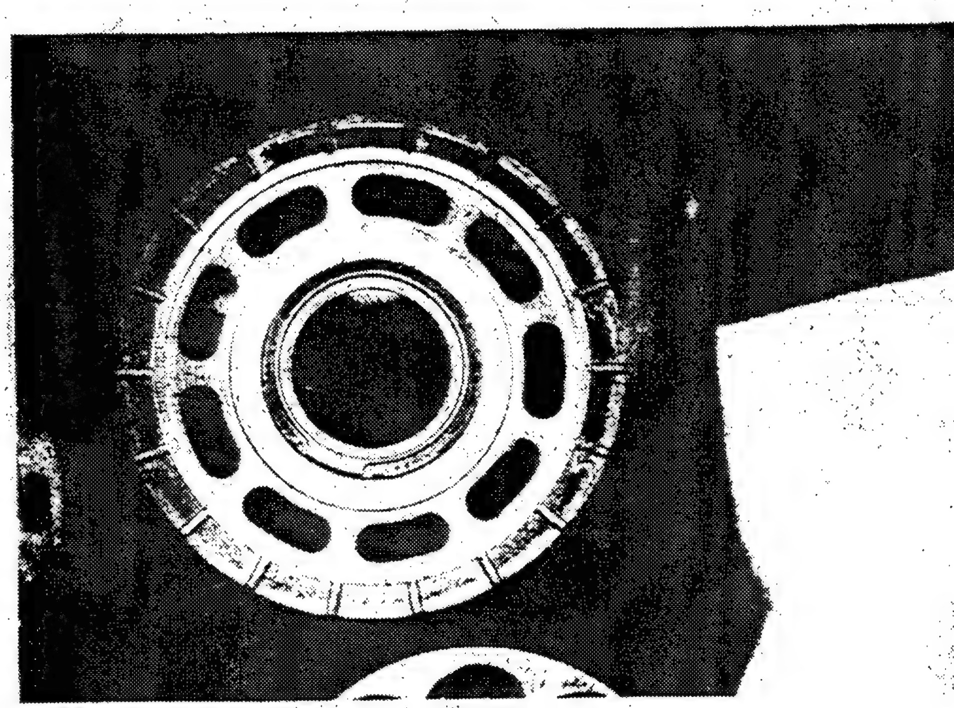


PISTON AND SHOE ASSEMBLY

S/N MX 441537B, PUMP #3
Photos dated 5 January 1995

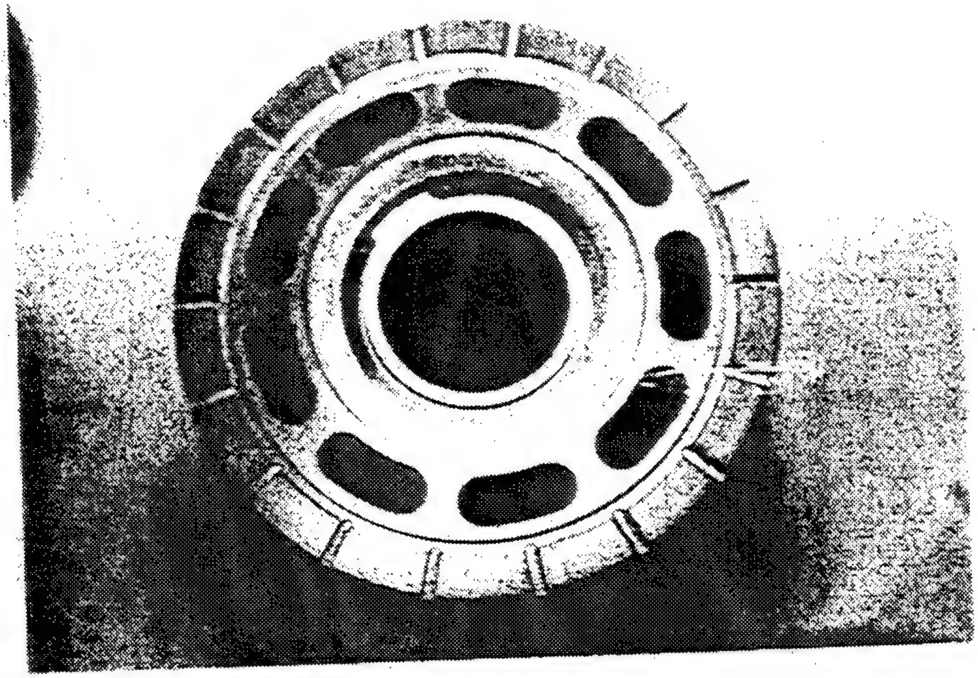


PISTON AND SHOE ASSEMBLY



CYLINDER BLOCK

S/N MX 473847B. PUMP #4.
Photos dated 15 May 1996



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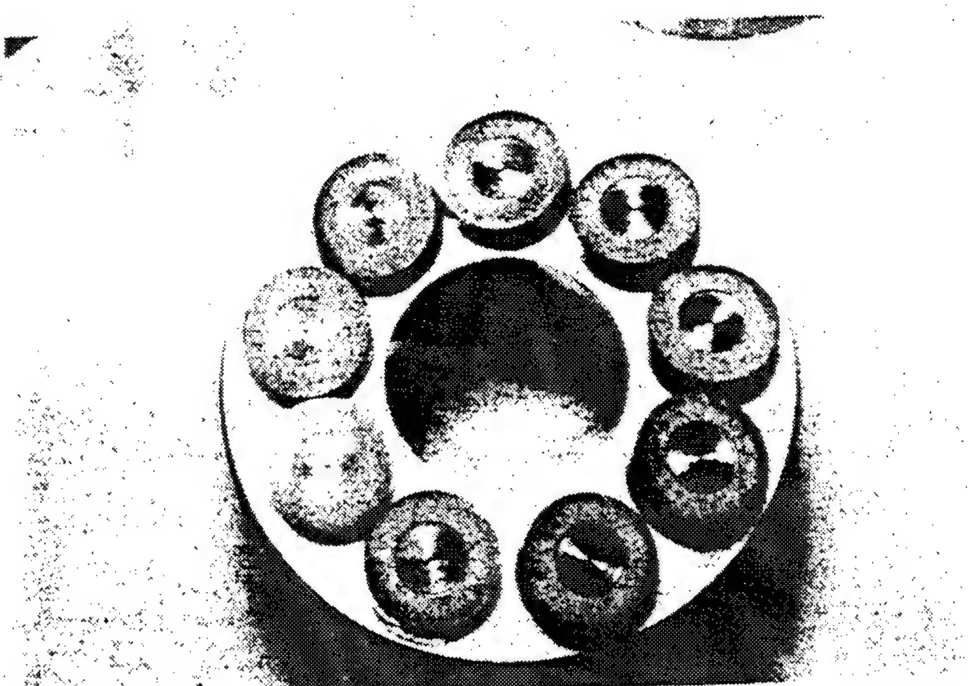
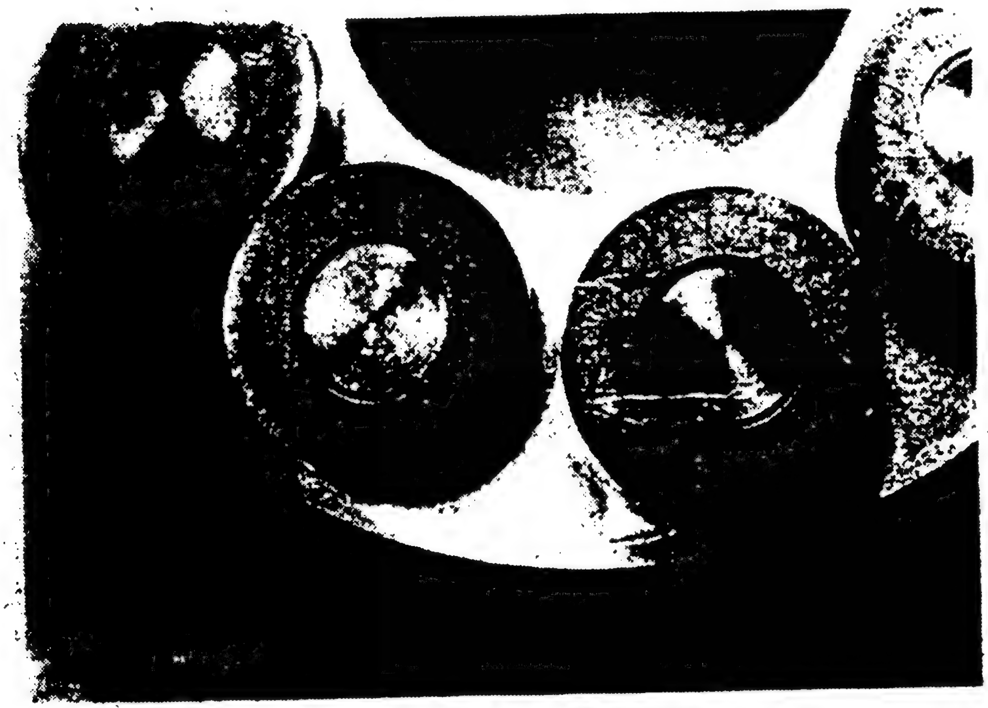


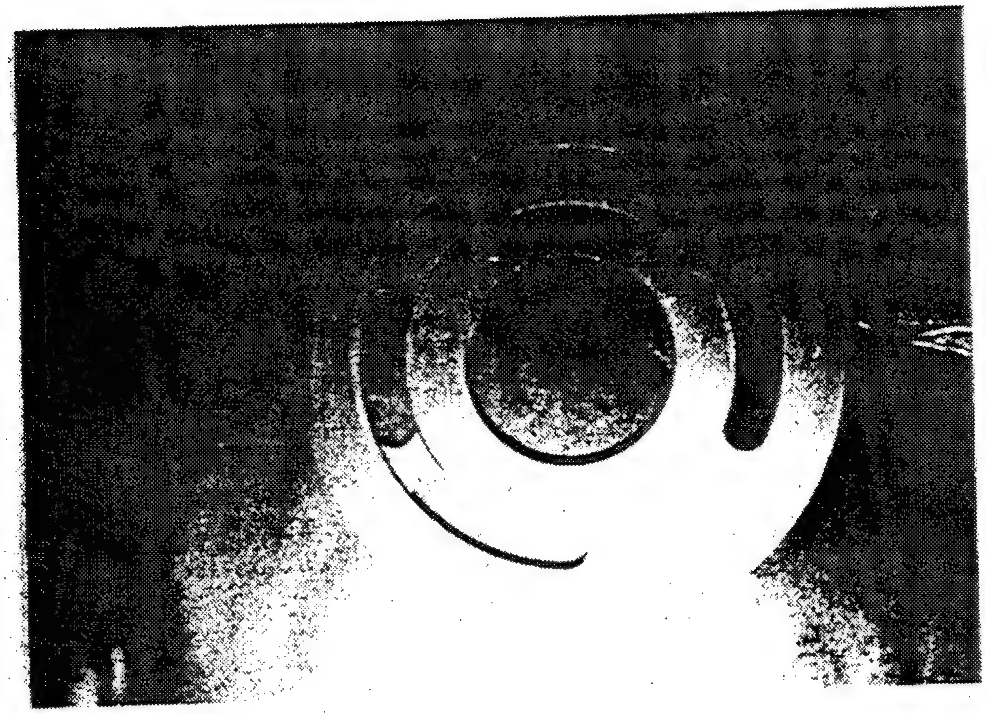
PISTON AND SHOE ASSEMBLY

S/N MX 473847B, PUMP #4
Photos dated 15 May 1996

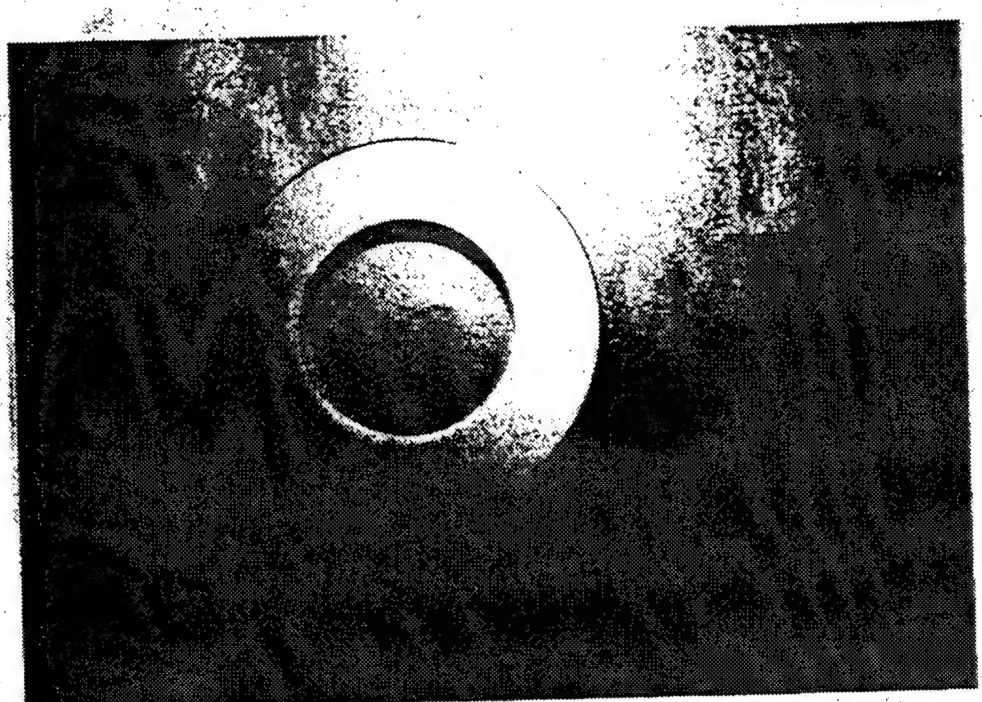


PISTON AND SHOE ASSEMBLY

S/N MX 473847B, PUMP #4
Photos dated 5 January 1995.



WAFER PLATE



SHAFT SEAL MATING RING

SCHMIDT

83232

OK

VICKERS, INCORPORATED TEST DATA

TEST STAND NO: 11

MODEL: ________________PV3-300-7B

(#3)

SERIAL NO: ____________MX441537B

TEST PROCEDURE NUMBER: _________ 7337

PARAGRAPH NUMBER: _____________ 3.5.11 - 3.5.2

TEST OPERATOR: 3273

DATE: 05-09-96 TIME: 10:54:47

		LIMIT	JAN 95	NOV 94
RPM	5283			
INLET PRESS ...	98.7			
INLET TEMP	193			
CASE PRESS	141.2			
CASE FLOW	3.88	4.5 - 5.9		
CASE TEMP	237			
OUTLET PRESS ..	4117			
OUTLET FLOW ...	65.1			
OUTLET TEMP ...	220			
EDV VOLTS	183.3			
EDV AMPS	0.00			
TORQUE	2000	2162	1890	1915

DIRECTION .... -
OUTLET S/O MAIN ..... O
OUTLET VOLUME L
EDV SOLENOID .... D

CKERS, INCORPORATED TEST DATA

:ST STAND NO: 11

DEL: ________________PV3-300-7B

:RIAL NO: ____________MX441537B

:ST PROCEDURE NUMBER: ________ 7337

ARAGRAPH NUMBER: _____________ 3.5.11 - 3.5.2.

:ST OPERATOR: 3273

ATE: 05-09-96 TIME: 10:51:11

		LIMIT	JAN 95	NOV 94
PM	5226			
NLET PRESS ...	101.4			
NLET TEMP	205			
:ASE PRESS	152.3	4.5	4.0	3.6
:ASE FLOW	4.43	5.9		
:ASE TEMP	244			
)UTLET PRESS ..	4127			
)UTLET FLOW ...	0.0			
)UTLET TEMP ...	214			
:DV VOLTS	183.4			
:DV AMPS	0.00			185
TORQUE	183	235	205	

DIRECTION .... –
OUTLET S/O MAIN C
OUTLET VOLUME L
EDV SOLENOID .... D

B-1 PUMP TEST PLAN

FLUIDS:	1. MIL-H-5606	BASE LINE
	2. MIL-H-87257	(ROYCO 777)
	3. ??	

DURATION:

STAGE I: 30 HRS AT 180F INLET

STAGE II: 30 HRS AT 210F INLET

STAGE III: 30 HRS AT 250F INLET

INSPECTIONS:

PRETEST AND AFTER EACH STAGE

FLUID SAMPLES:

AT 0, 6, 15 AND 30 HRS OF EACH STAGE

PATCH FILTER: AFTER EACH STAGE

B-1 PUMP TESTS WITH MIL-H-5606 & MIL-H-87257

- **BOTH TESTS SUCCESSFUL**
- **STABLE OPERATION**
  - **NO CHANGE IN OUTLET PRESSURE**
  - **CASE DRAIN FLOW INCREASED FOR MIL-H-5606**
- **BOTH PUMPS LOOKED LIKE NEW AFTER THE TESTS**
  - **NO SIGN OF CAVITATION OR WEAR**
- ***MIL-H-87257 PERFORMED AS GOOD AS OR BETTER THAN MIL-H-5606***

SUMMARY

- MIL-H-5606 AND MIL-H-87257 TESTED IN B-1 HYDRAULIC PUMPS UNDER IDENTICAL CONDITIONS

- NO CAVITATION OR WEAR OBSERVED ON EITHER PUMP

- BOTH FLUIDS PERFORMED EQUALLY WELL EXCEPT

  VISCOSITY OF MIL-H-5606 REDUCED BY 50% DURING THE FIRST 30 *HOURS*

- MIL-H-87257 HAS BETTER LUBRICITY THAN MIL-H-5606

- MIL-H-87257 IS READY TO FLY!!!!!

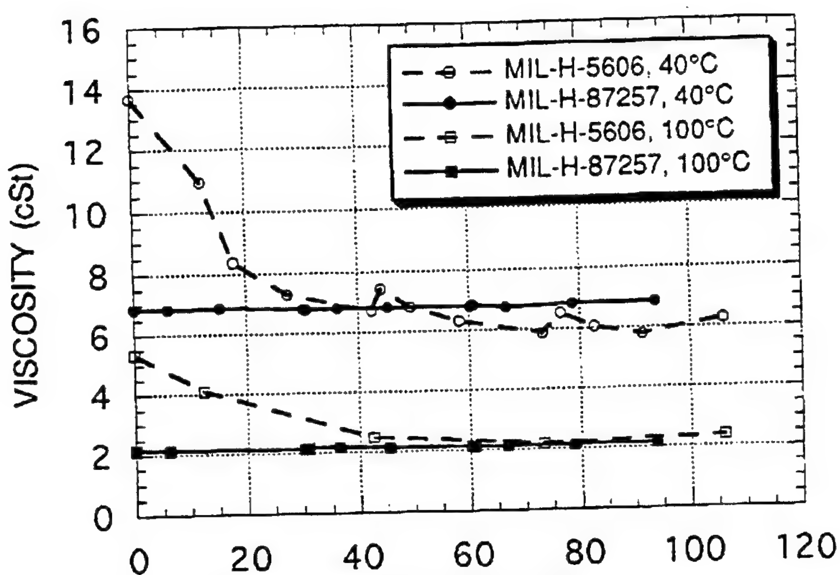


Figure 4. Viscosity loss in B-1 pump tests

4. CONCLUSIONS AND RECOMMENDATIONS

The B-1B was successfully flown for 365.9 hours using MIL-H-87257 hydraulic fluid. All hydraulic pump test results were acceptable. The disassembly and inspection confirmed the lack of any unusual wear. The acceptable test results indicate MIL-H-87257 hydraulic fluid may be used as a replacement for MIL-H-5606.

B-1B Hydraulic Pump Tests with MIL-PRF-87257

Shashi Sharma

Materials and Manufacturing Directorate
Air Force Research Laboratory, WPAFB

B1-B Hydraulic Pump Tests with MIL-PRF-87257

- Testing Under PRAM Project
- Pump Tests at WPAFB

B1-B Hydraulic Pump Tests with MIL-PRF-87257

PRAM Project for MIL-PRF-87257 Evaluation

1. Rockwell Testing
   - Hydraulic Lab Component Tests
   - Flight Control Simulator

2. Subcontractor Testing
   - Sterer: Nose Wheel Steering
   - Gull: Fluid Quantity Gaging System
   - Speco: Rotary Launcher Drive
   - Vickers : Hydraulic Pumps - Key to Transition

B1-B Hydraulic Pump Tests with MIL-PRF-87257

B-1B Pump Tests at Vickers

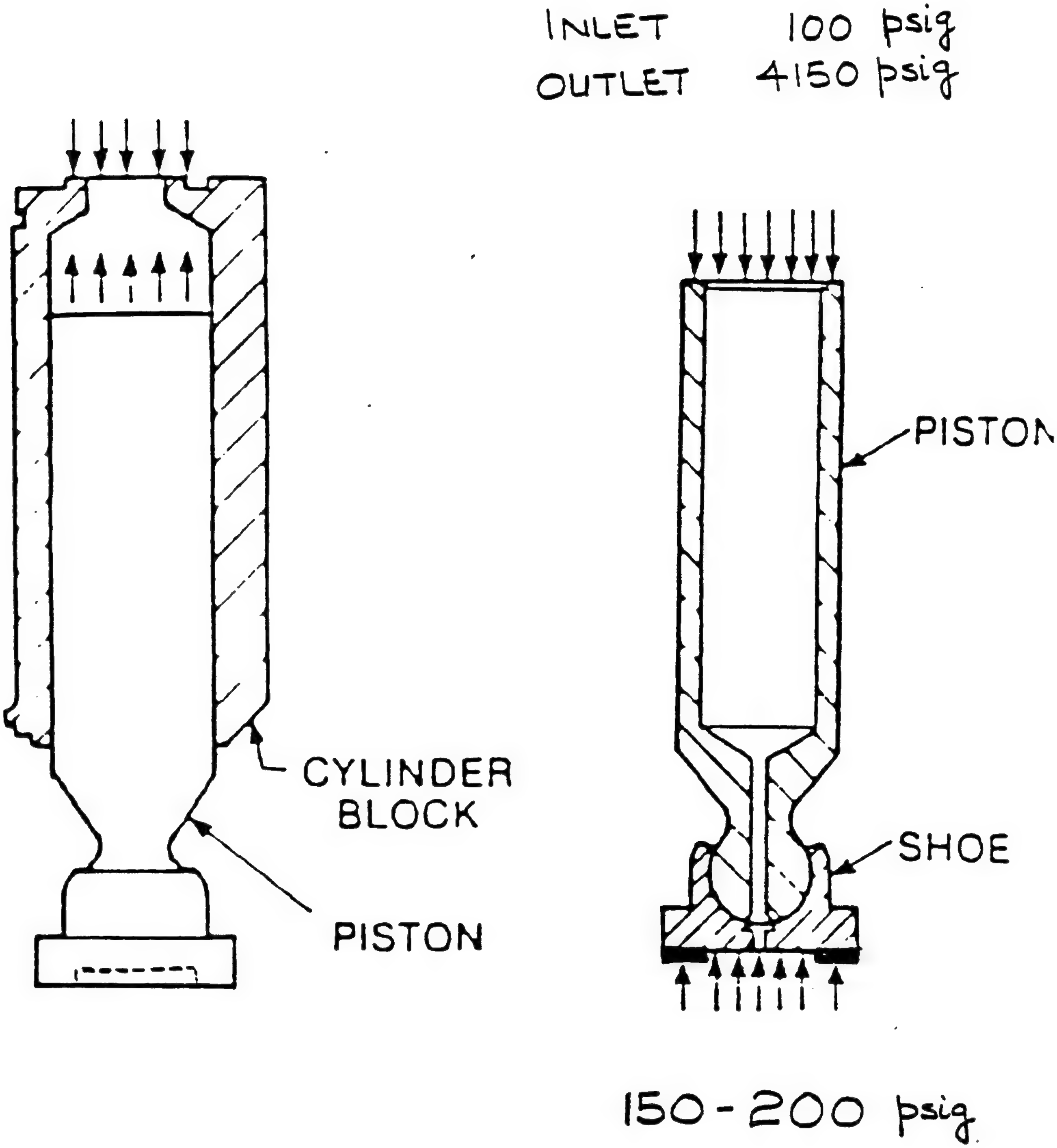
Fluid: MIL-PRF-87257 (Fire-Resistant)

	Test 1	Test 2
Inlet Temp (°F)	275	210
Main Flow (Gpm)	64.5	64.5
Duration (Hr)	7.5	37.5

Test 1: Catastrophic Failure of Piston Shoes

Test 2: Metal Particles Seen in Patch Test,
Erosion on Piston Shoe Faces.
Test Discontinued

Note: Base Line Tests With Mil-H-5606 were not Performed



INLET 100 psig
OUTLET 4150 psig
PISTON
CYLINDER BLOCK
SHOE
PISTON
150 - 200 psig

B1-B Hydraulic Pump Tests with MIL-PRF-87257

Summary of PRAM Project

- MIL-PRF-87257 Fully Successful Except Pump Tests

  Only Question: Poor Pump Performance at Vickers

- Without Successful Pump Testing MIL-PRF-87257 Could Not Be Transitioned

- No PRAM Funds to Continue Pump Testing

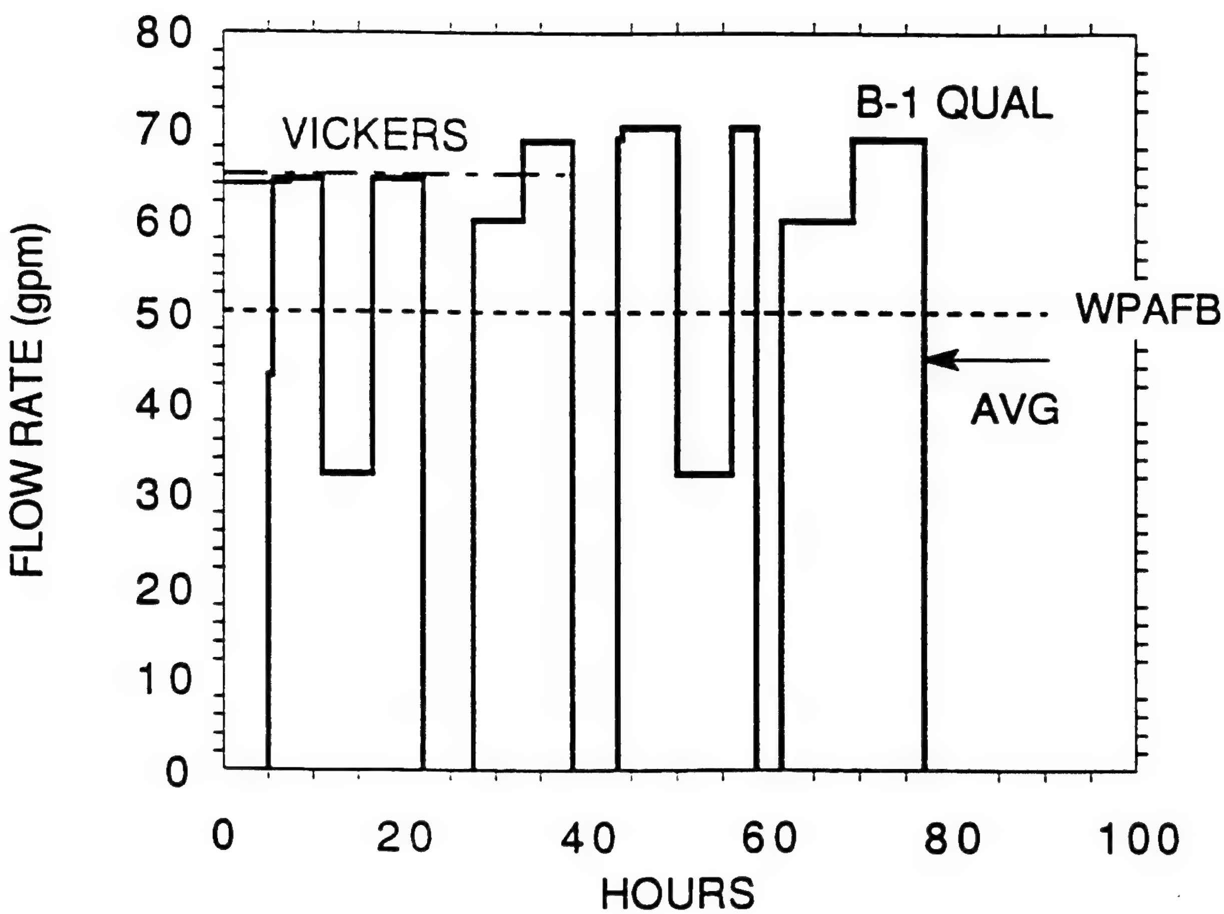
- AFRL/MLBT Took Initiative to Conduct Necessary Pump Tests

B1-B Hydraulic Pump Tests with MIL-PRF-87257

Pump Tests at WPAFB

- Realistic Test Conditions
- Base Line Test With Mil-H-5606
- Parallel Fluid Analyses
- Concurrence of All Stakeholders (ACC, Oklahoma ALC, PRAM, EN, Rockwell, Vickers)

PUMP TESTS FLOW RATES



B1-B Hydraulic Pump Tests with MIL-PRF-87257

Pump Tests at WPAFB

Fluids: 1. MIL-H-5606 Base Line

2. MIL-PRF-87257

Duration: Stage I: 30 Hrs at 180°F Inlet

Stage II: 30 Hrs at 210°F Inlet

Stage III: 30 Hrs at 250°F Inlet

Inspections: Pretest and After Each Stage

Fluid Samples: At 0, 6, 15 and 30 Hrs of Each Stage

Patch Filter: After Each Stage

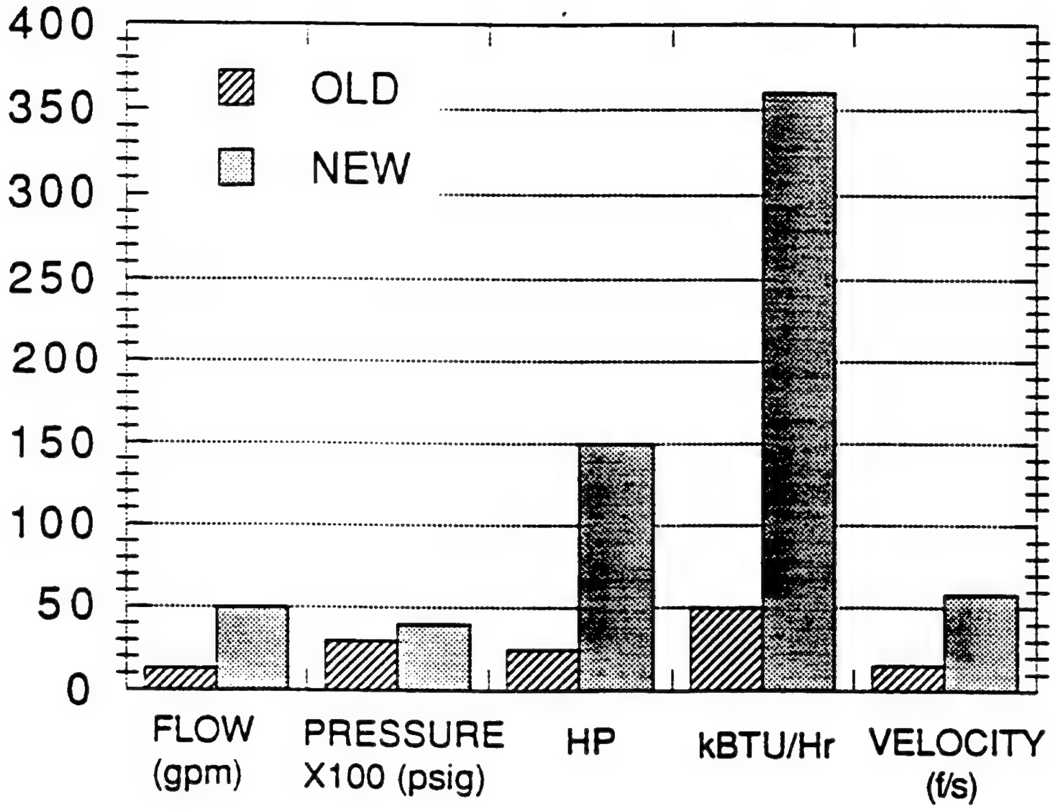
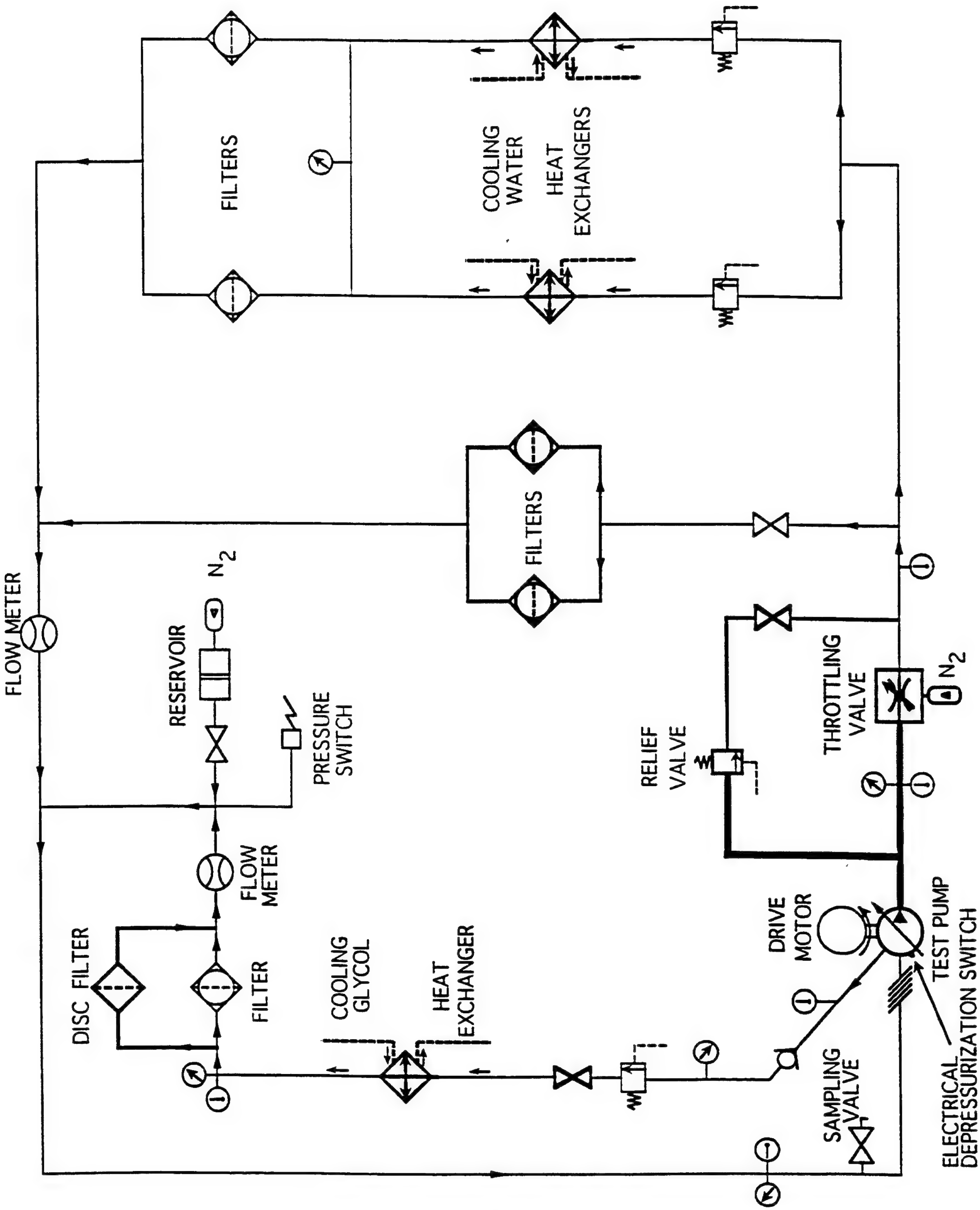


Figure 1. Hydraulic pump test stand configurations



FILTERS
COOLING WATER HEAT EXCHANGERS
FILTERS
FLOW METER
RESERVOIR
N_2
PRESSURE SWITCH
RELIEF VALVE
THROTTLING VALVE
N_2
DISC FILTER
FILTER
FLOW METER
COOLING GLYCOL HEAT EXCHANGER
DRIVE MOTOR
TEST PUMP
SAMPLING VALVE
ELECTRICAL DEPRESSURIZATION SWITCH

B1-B Hydraulic Pump Tests with MIL-PRF-87257

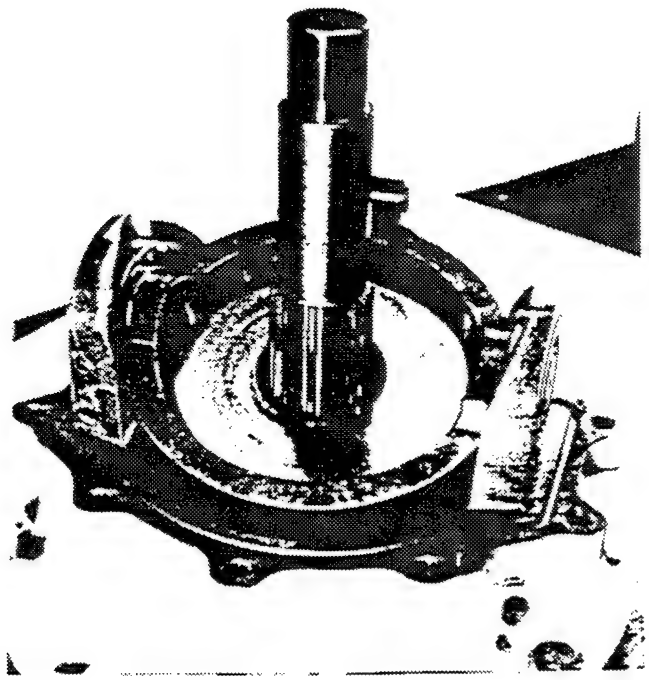
Test Parameters

- Pump: Vickers PV3-300-7B
- Pump Outlet Pressure 4150 psig
- Pump Inlet Pressure 95-100 psig
- Main Flow Rate: 50 gpm
- Pump Speed 5250 rpm
- Duration:

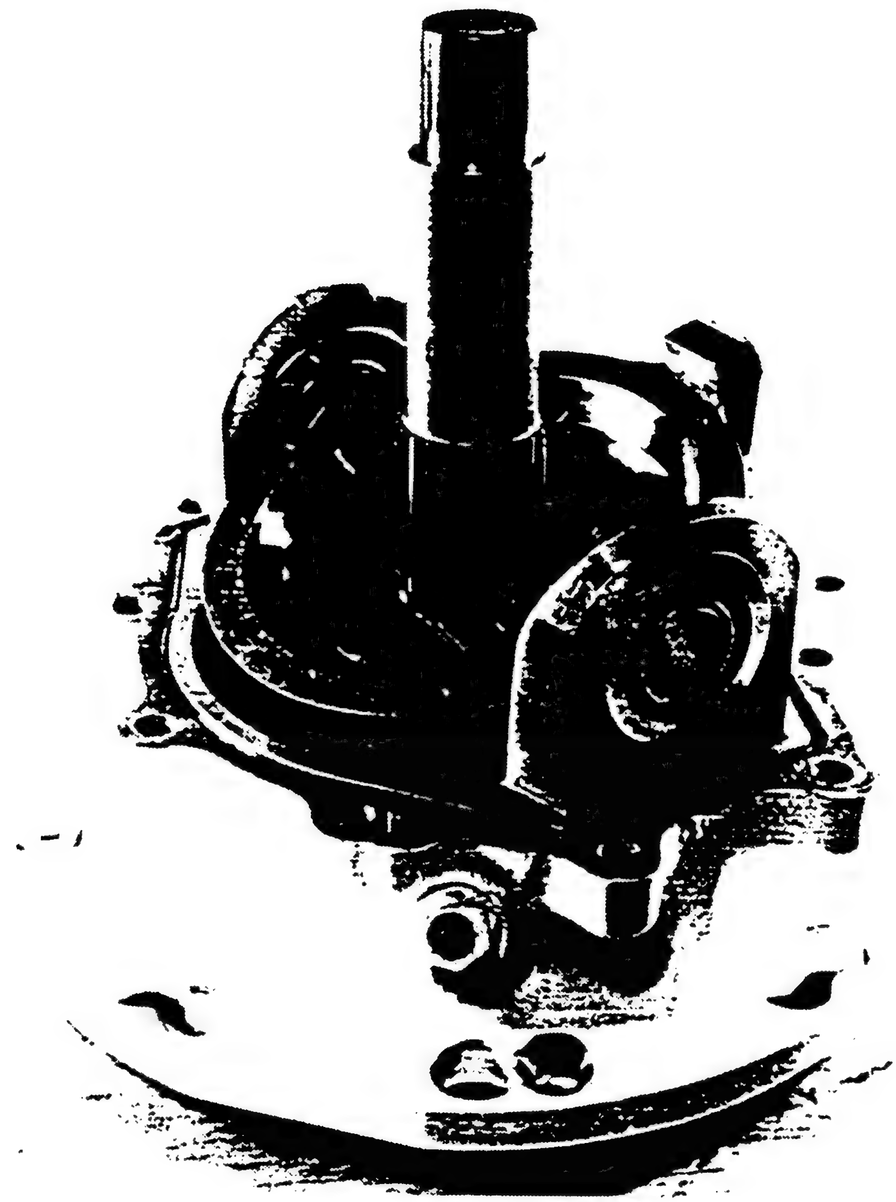
  Stage I: 30 Hrs at 180°F Inlet

  Stage II: 30 Hrs at 210°F Inlet

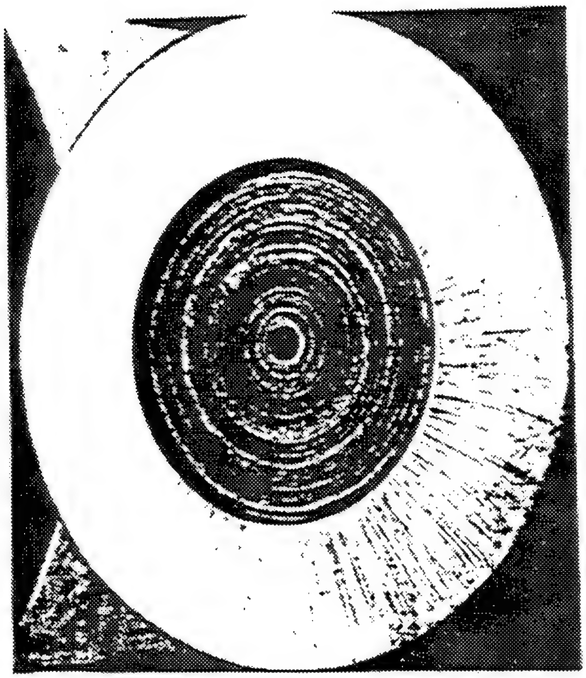
  Stage III: 30 Hrs at 250°F Inlet



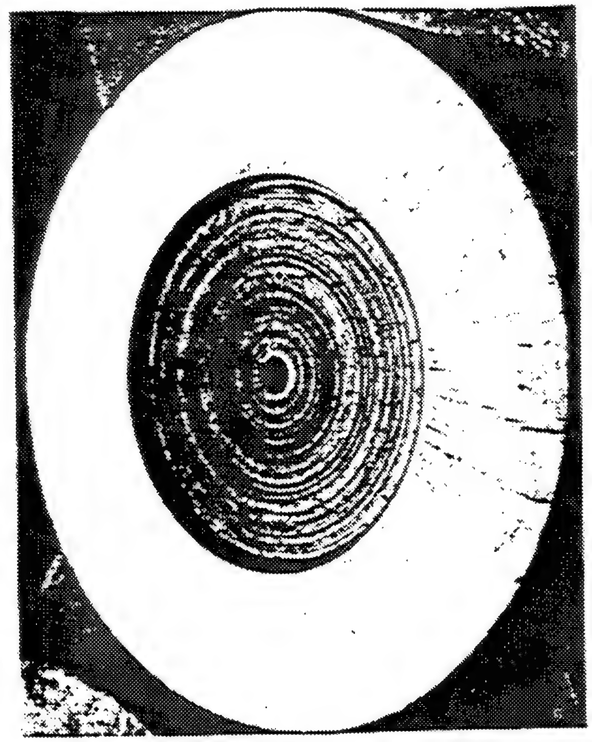
Partial Assembly of Test Pump after Stage II
Pump Test 33 with MIL-H-5606F



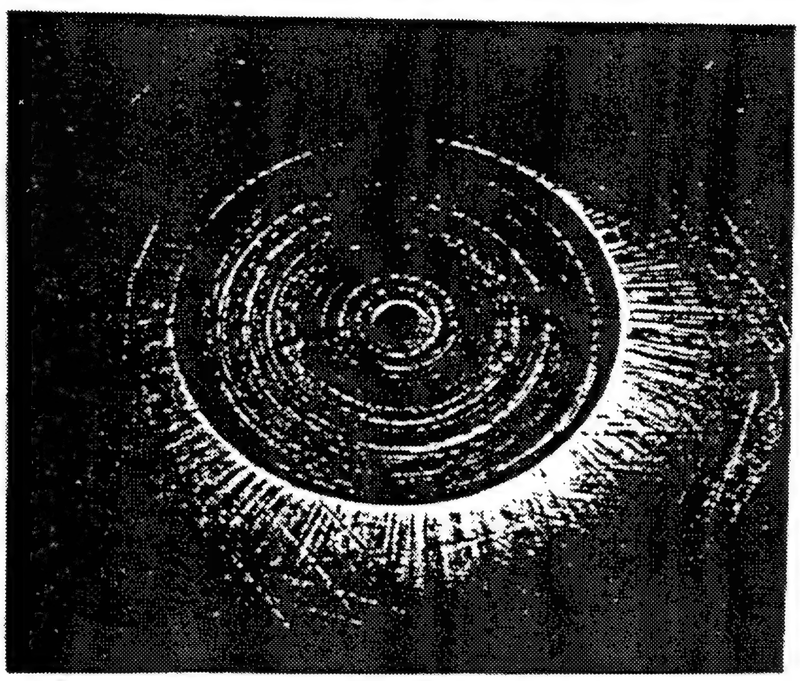
Partial Assembly of Test Pump at Pretest
Pump Test 34 with MIL-H-87257



Stage I



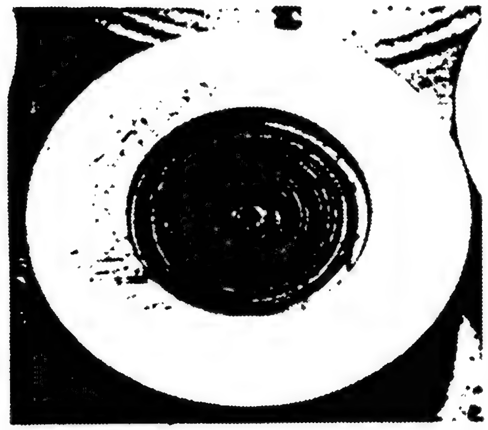
Stage II



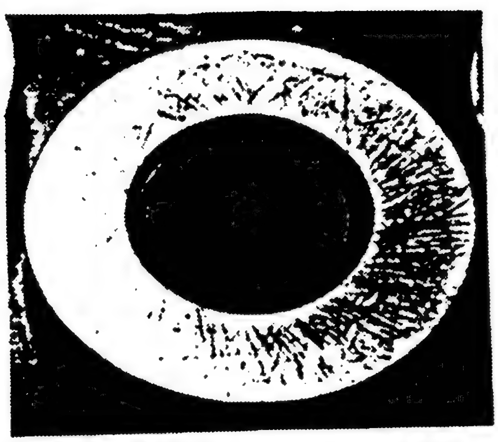
Stage III

Piston 1 Shoe Face After Stages I, II, and III
Pump Test 33 with MIL-H-5606F

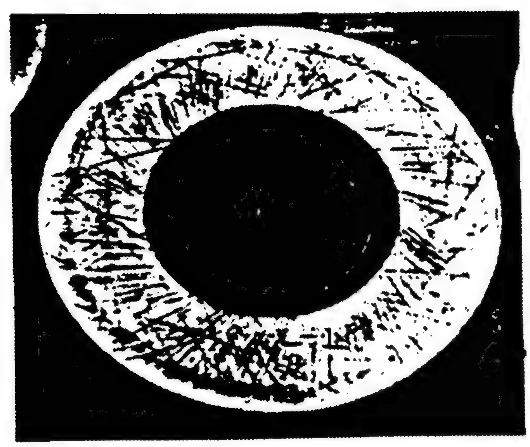
Pretest



Stage I

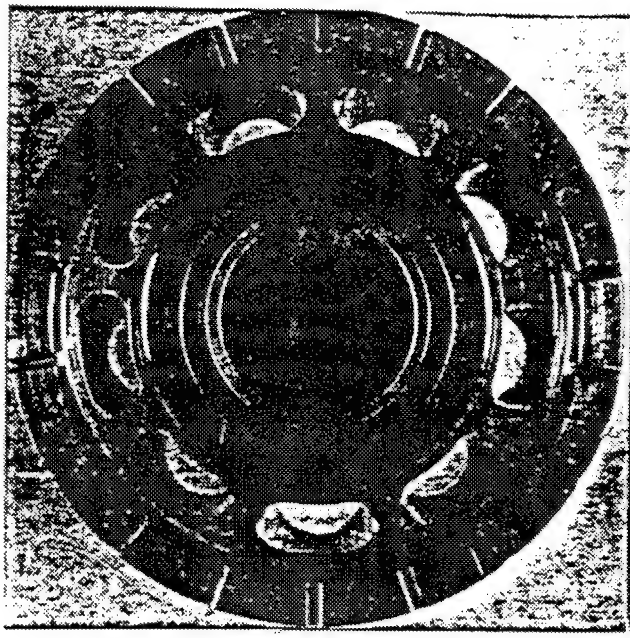


Stage II

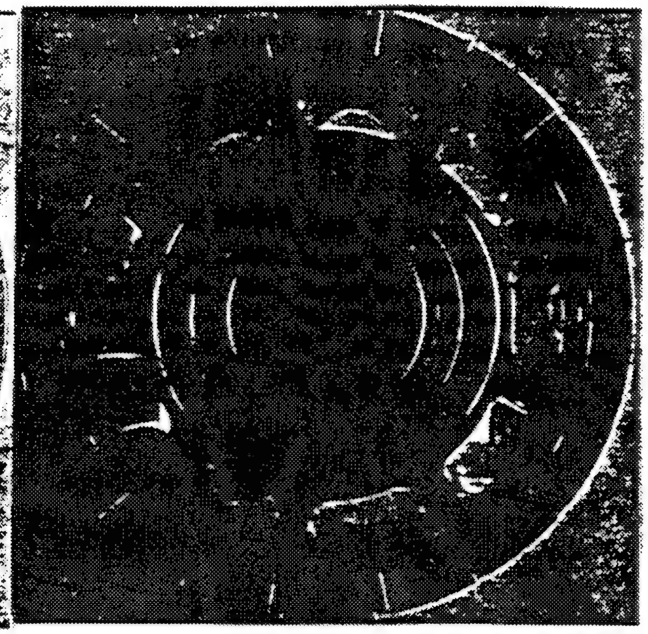


Stage III

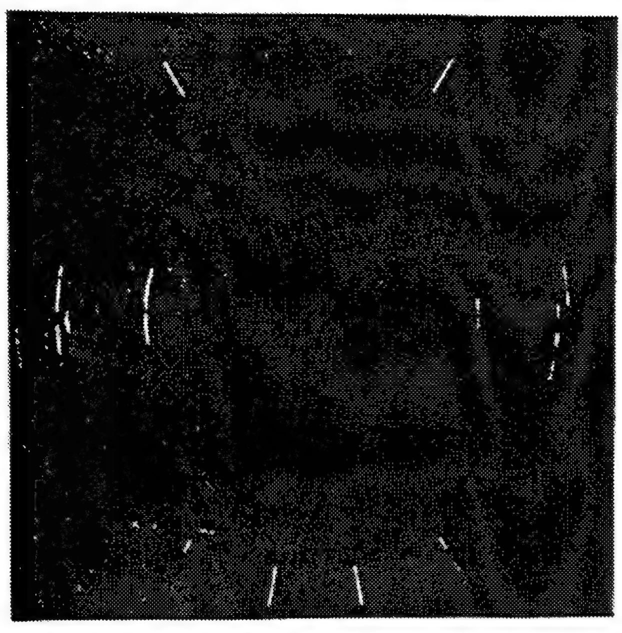
Piston 1 Shoe Face at Pretest, and After Stages I, II, and III
Pump Test 34 with MIL-H-87257



Stage I

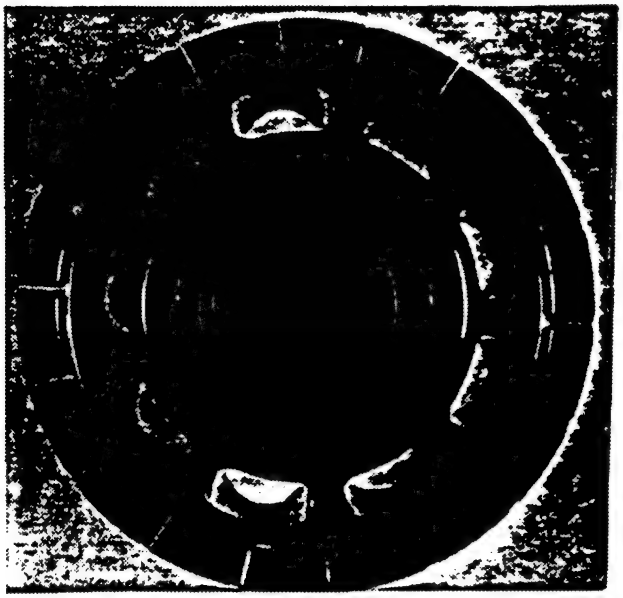


Stage II

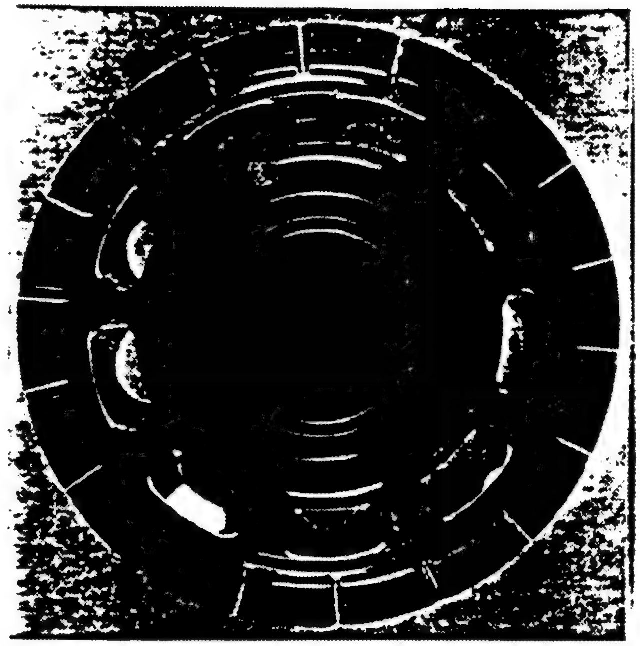


Stage III

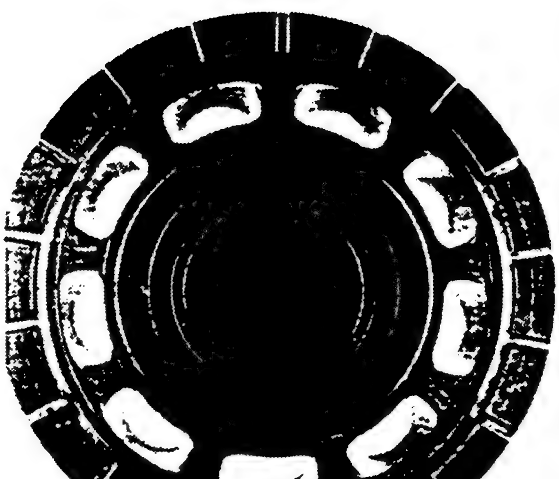
Cylinder Block Face after Stage I, II and III
Pump Test 33 with MIL-H-5606F



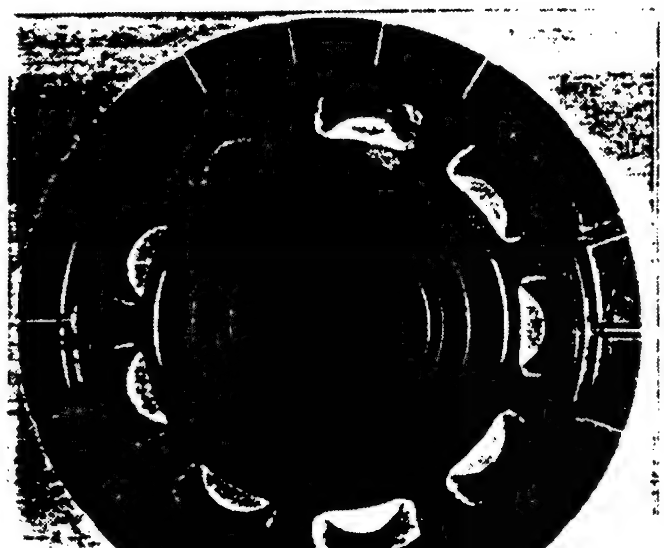
Pretest



Stage I



Stage II



Stage III

Cylinder Block Face at Pretest and after Stage I, II, and III
Pump Test 34 with MIL-H-87257

B1-B Hydraulic Pump Tests with MIL-PRF-87257

Pump Test Results

- MIL-PRF-87257 and MIL-H-5606 Tests Successful
- Stable Operation
  - No Change in Outlet Pressure
  - Case Drain Flow Increased for MIL-H-5606
- Both Pumps Looked Like New After the Tests
  - No Sign of Cavitation or Wear

B1-B Hydraulic Pump Tests with MIL-PRF-87257

Analyses of Fluid Samples

Samples at: 0, 6, 15 and 30 Hrs of Each Stage for Both Fluids

- Viscosity at 40°C and 100°C
- Water Content
- Acid Number
- Lubricity by 4-Ball Wear Test
- Wear Metal Analysis (19 Metals)

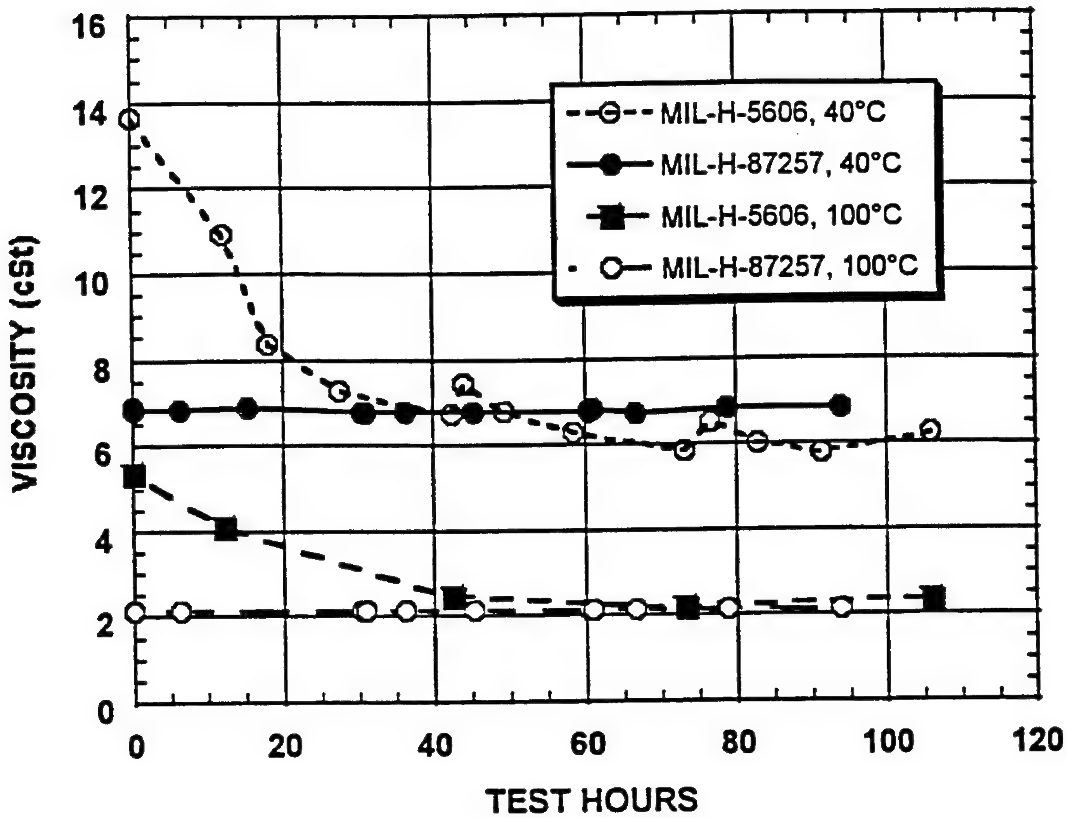


Figure 4. Viscosity change in B-1 pump tests

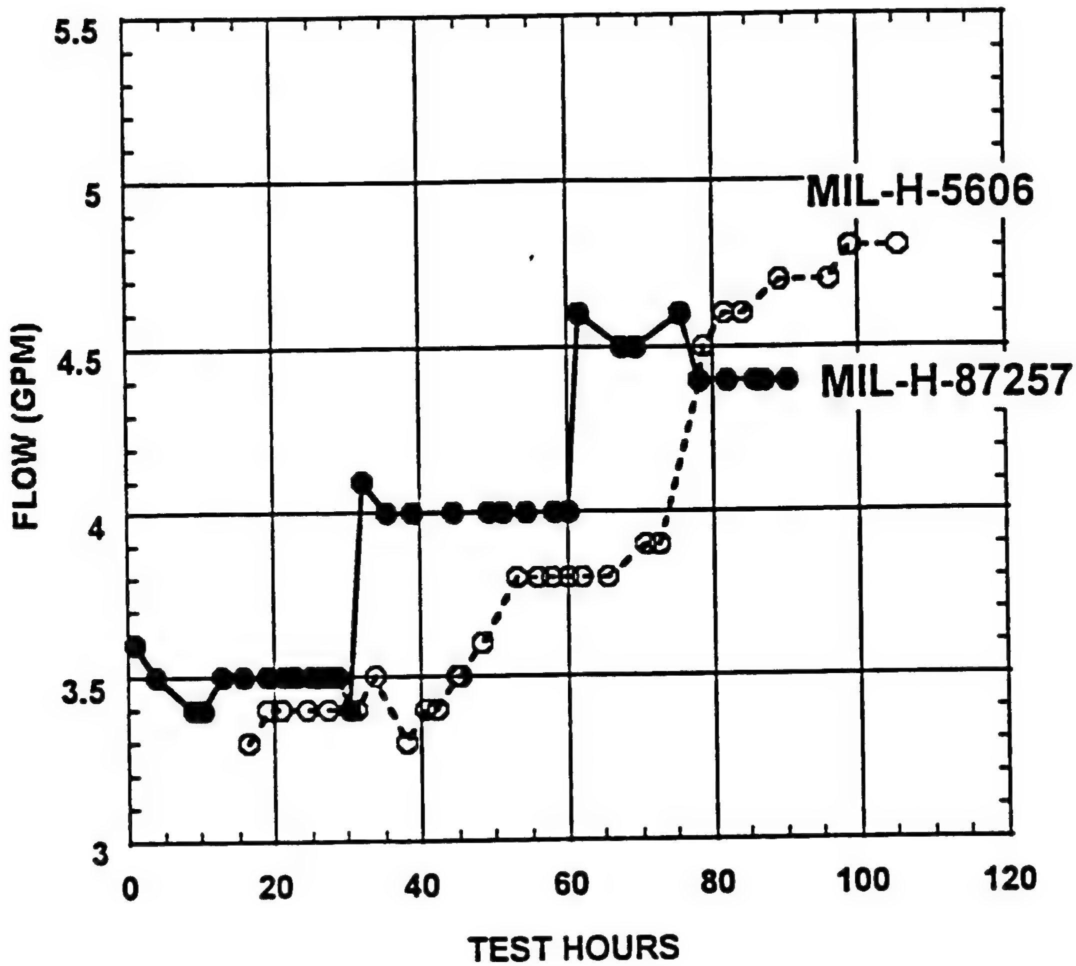


Figure 3. Case drain flow in B-1 pump tests

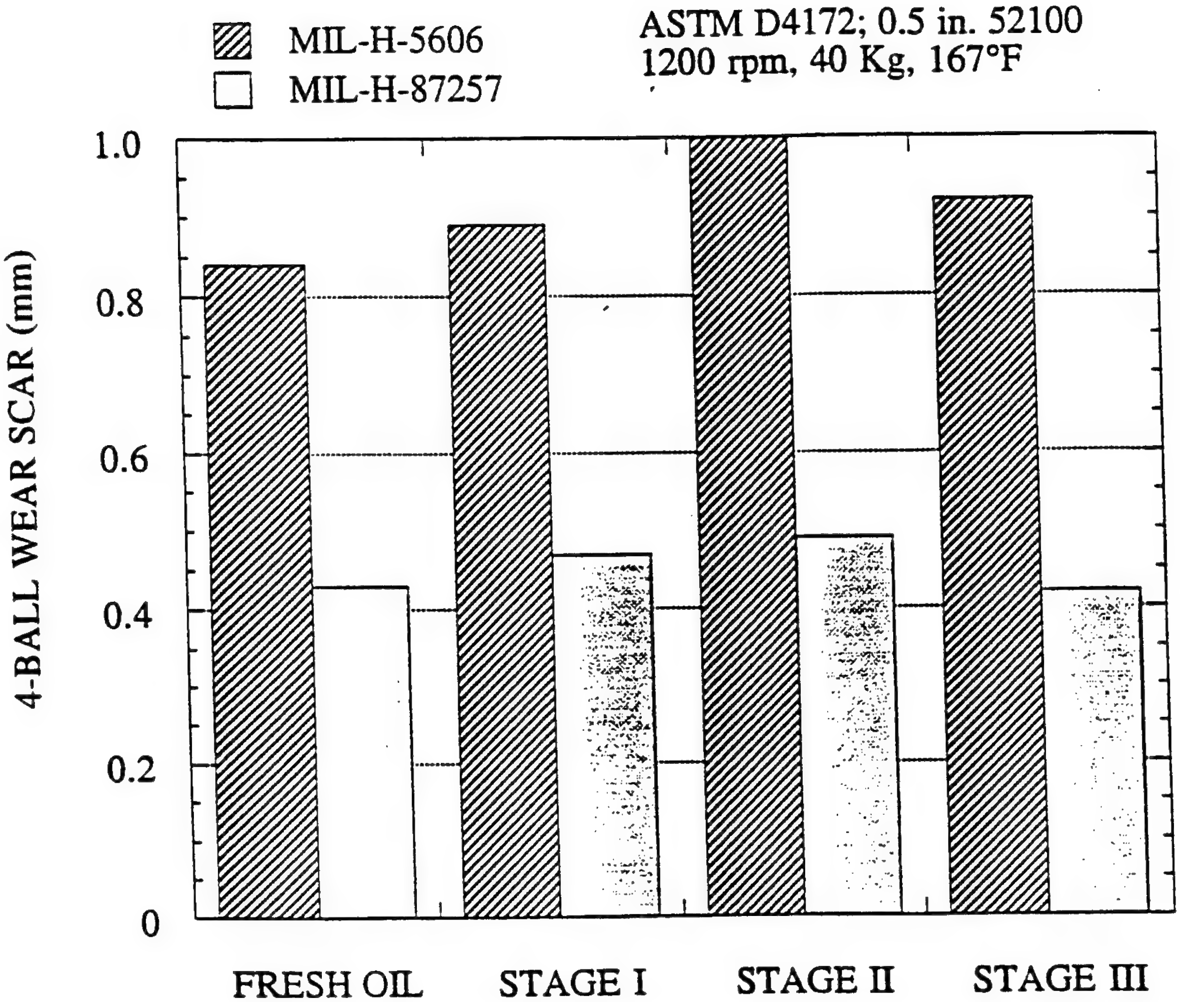


Figure 5. Four-Ball Wear Scar with B-1 Pump Test Fluid Samples

B1-B Hydraulic Pump Tests with MIL-PRF-87257

Summary

- MIL-PRF-87257 and MIL-H-5606 Tested in B-1 Hydraulic Pumps under Identical Conditions
- No Sign of Cavitation or Wear in Either Pump
- Both Fluids Performed Equally well except
  - Viscosity of MIL-H-5606 Reduced by 50% During the First 30 Hours
- MIL-PRF-87257 Has Better Lubricity than MIL-H-5606
- *MIL-PRF-87257 Performed as Well as or Better than MIL-H-5606 and*

Ready to Fly!!!!!

B1-B Hydraulic Pump Tests with MIL-PRF-87257

- Test Results Presented at Tinker AFB, OK-City in May-1993 in Presence of:

  ACC, AMC, OK-City ALC, Rockwell, Vickers

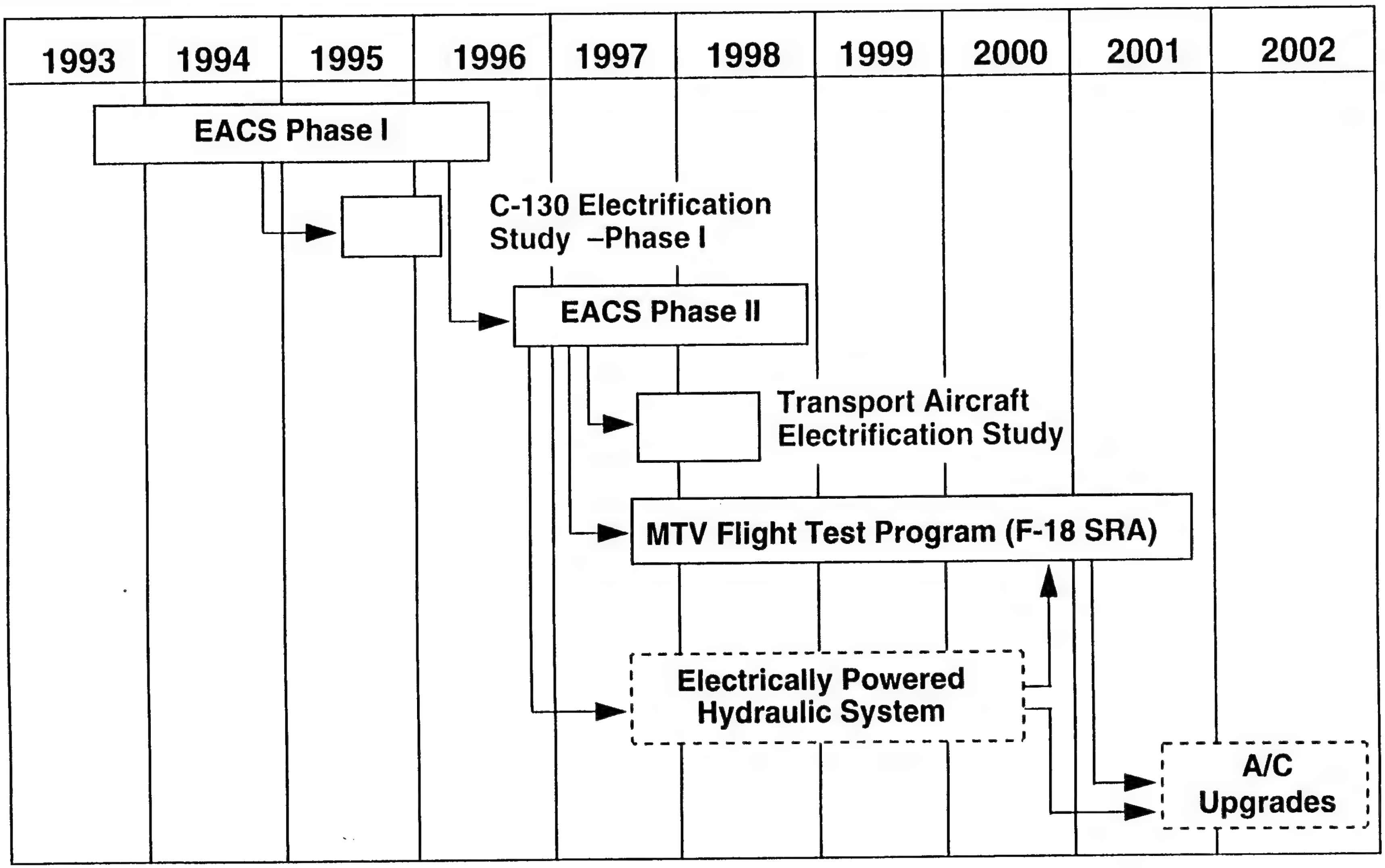
- Consensus Reached to Flight Test KC-135 and B-1 Aircraft With MIL-PRF-87257

Electric Actuation and Controls Technology

Boeing North American Inc.
Seal Beach, CA

David E. Blanding
March 10, 1997

Boeing Electric Actuation Development Plan

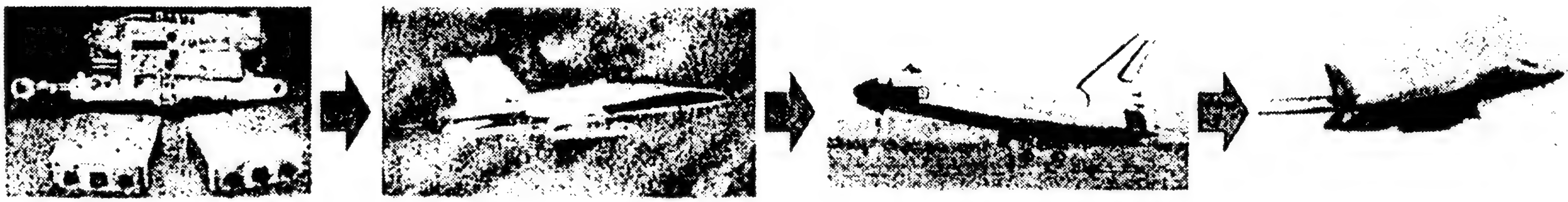


PPC_97_0035-04

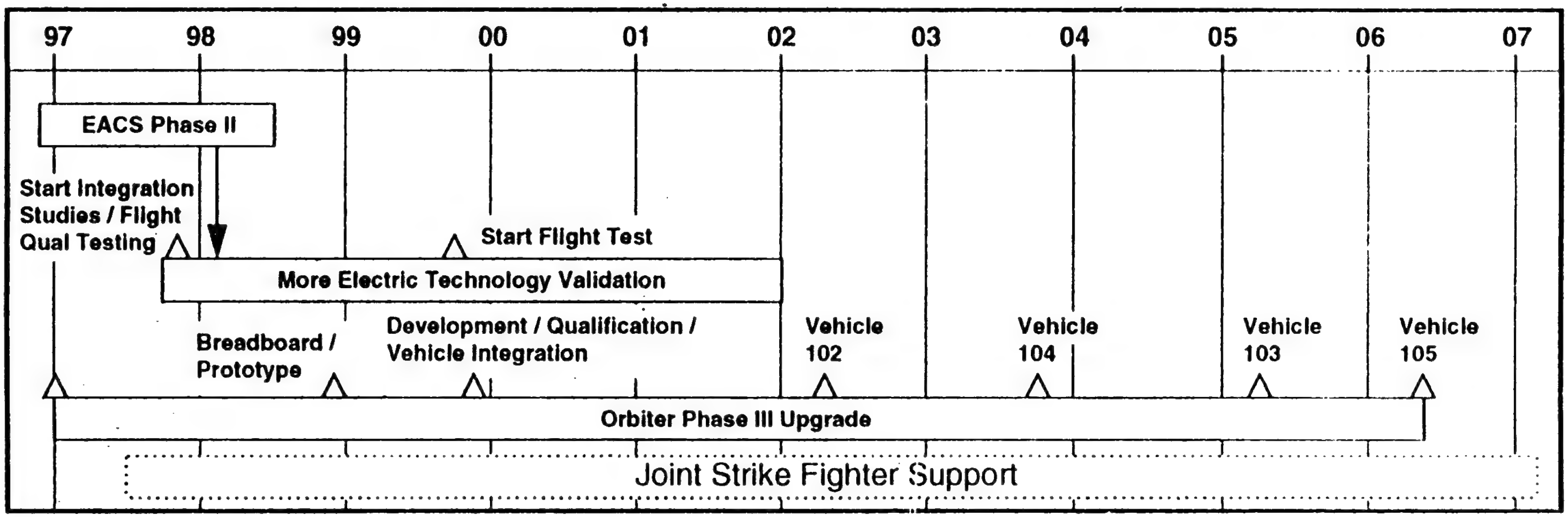
BOEING NORTH AMERICAN PROPRIETARY DATA

Boeing North American Electric Actuation Implementation Roadmap

- Develop and package a flight worthy, large flight critical surface electric actuator
  - Reduce cost
  - Improve reliability and maintainability



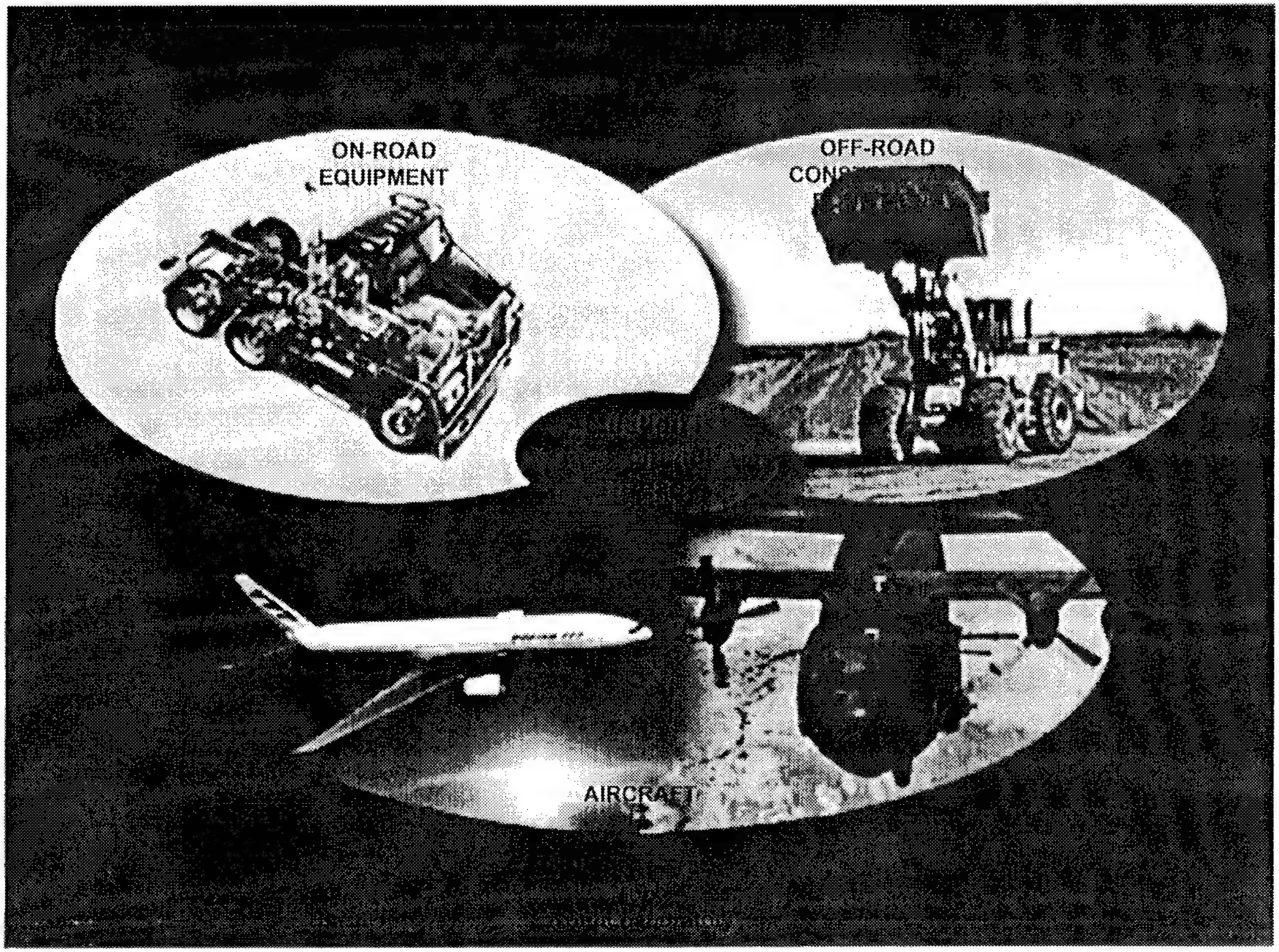
Electric actuator and motor drives



Boeing North American, Inc.
North American Aircraft Division
PROPRIETARY DATA

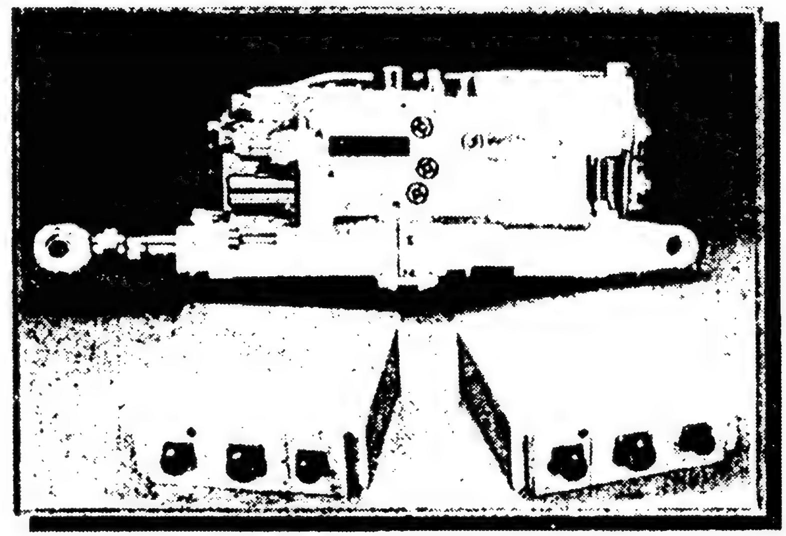
PPC-97-0005-043

Technology Reinvestment Program



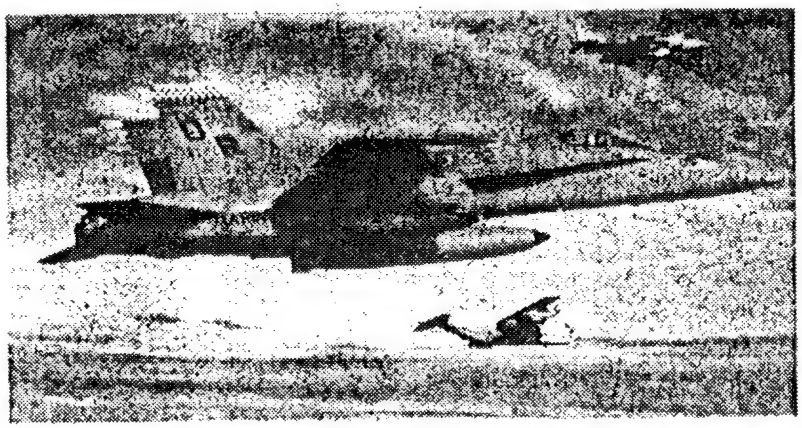
EACS Phase I – EHA System Performance

- 30,000 lbs nominal stall force
- 400 in. / sec2 maximum no-load acceleration
- 8.5 in. / sec maximum no-load velocity
- 7.12 in. total stroke (34.0 in. pin-to-pin mid-stroke)
- 23 hp maximum output power (39 hp corner)
- 5 Hz nominal response bandwidth
- >225,000 lbs / in. infinite frequency stiffness (one actuator piston bypassed)



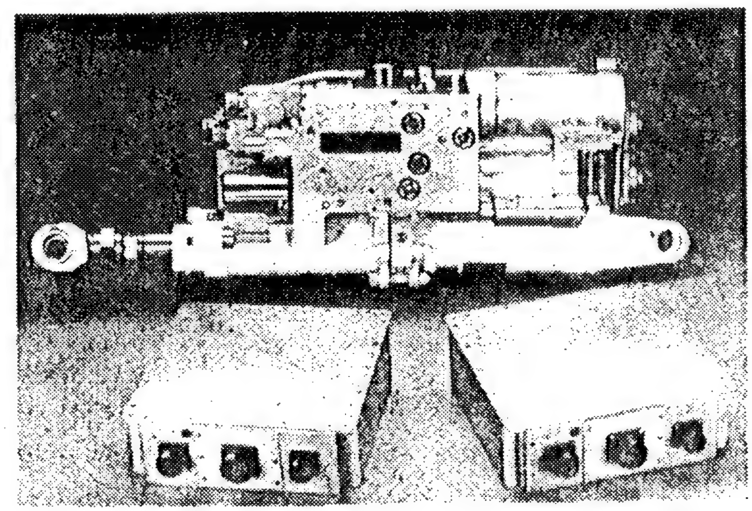
BNA's EHA Development for Large Critical Flight Control Surfaces

BNA/NAAD — Defense & Space Group

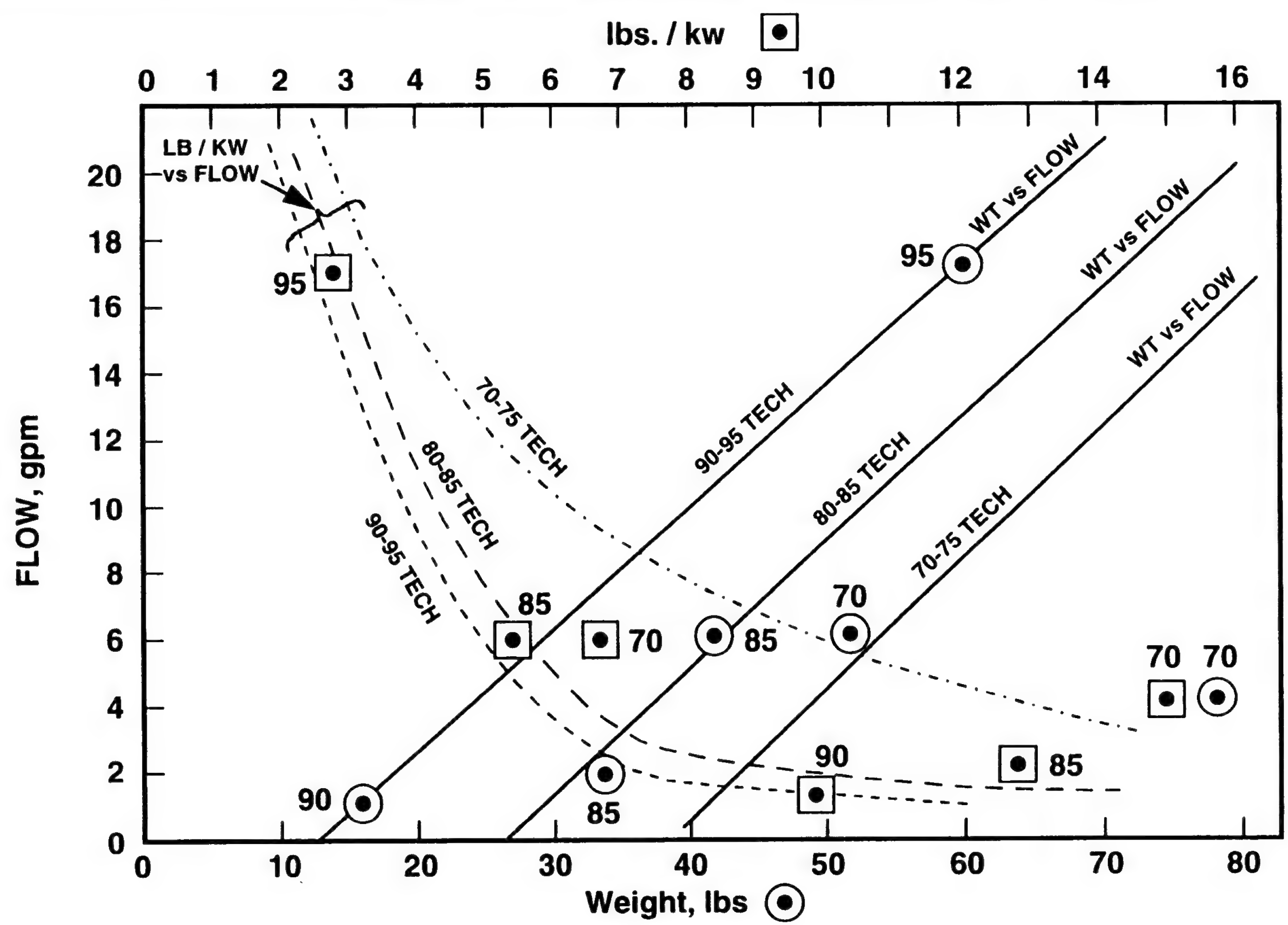


- DARPA funded TRP
- Fault tolerant-dual redundant
- Triplex
- ~438 horsepower
- Ground test in progress
- Flight test by year 2000

- Boeing North American
- Moog Controls
- Wright Laboratory



Power Pack Weight

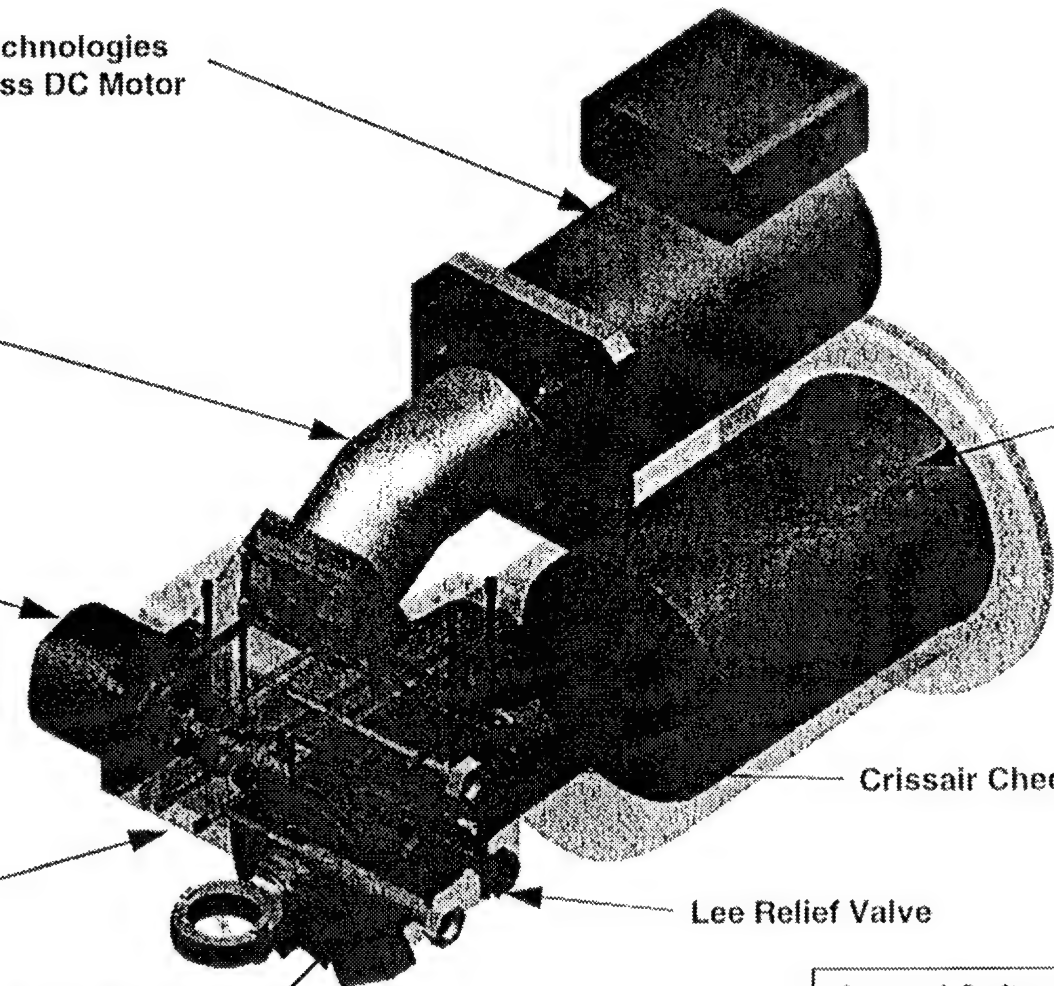


Boeing North American, Inc.
North American Aircraft Division
PROPRIETARY DATA

PPC-97-0005-045

Commercial EHA CATIA Model

BOEING



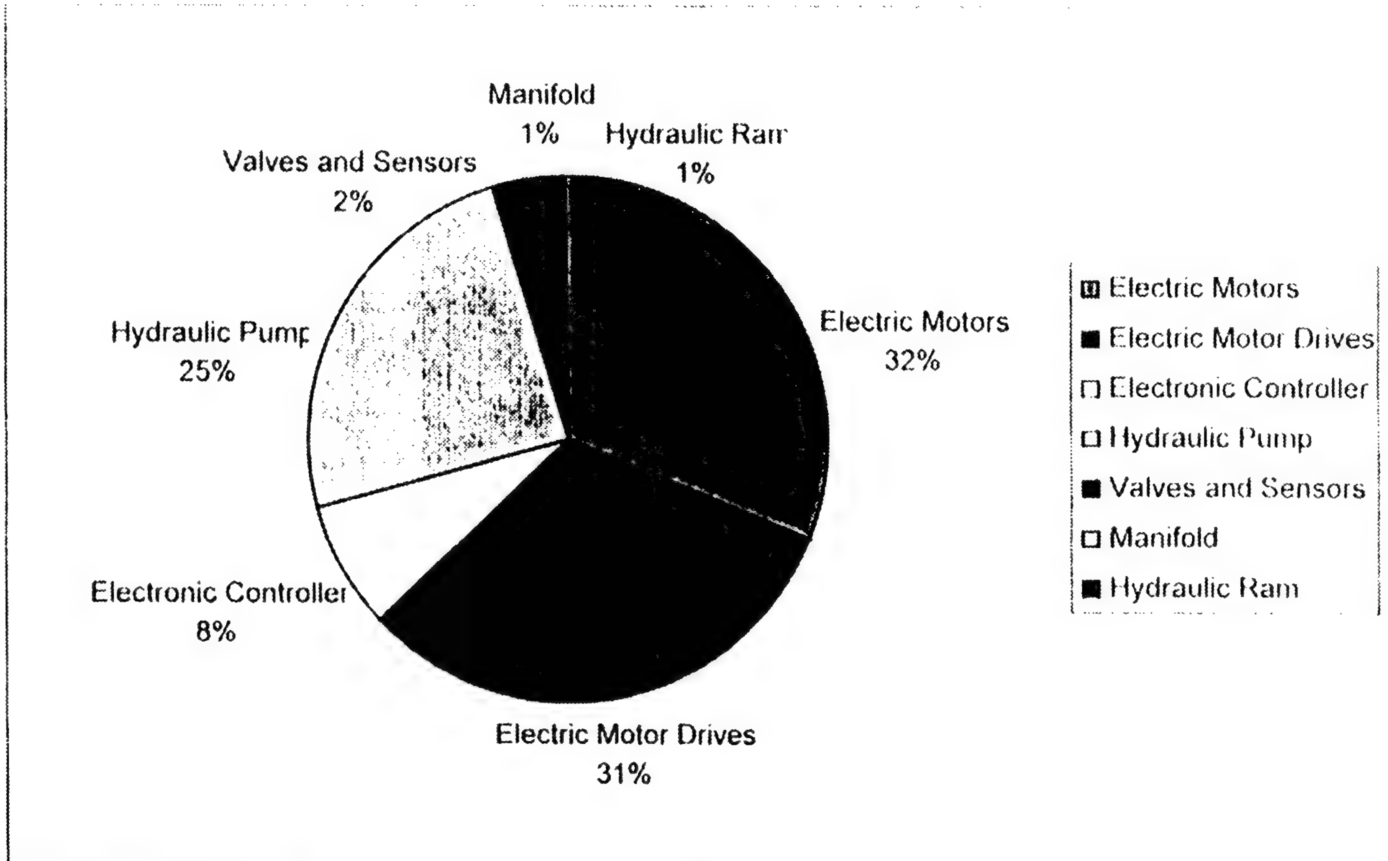
Control Software Boeing/Rockwell Science Center

PCC_97_0036_28

We are Evaluating Major Cost Drivers for EHA's

BOEING

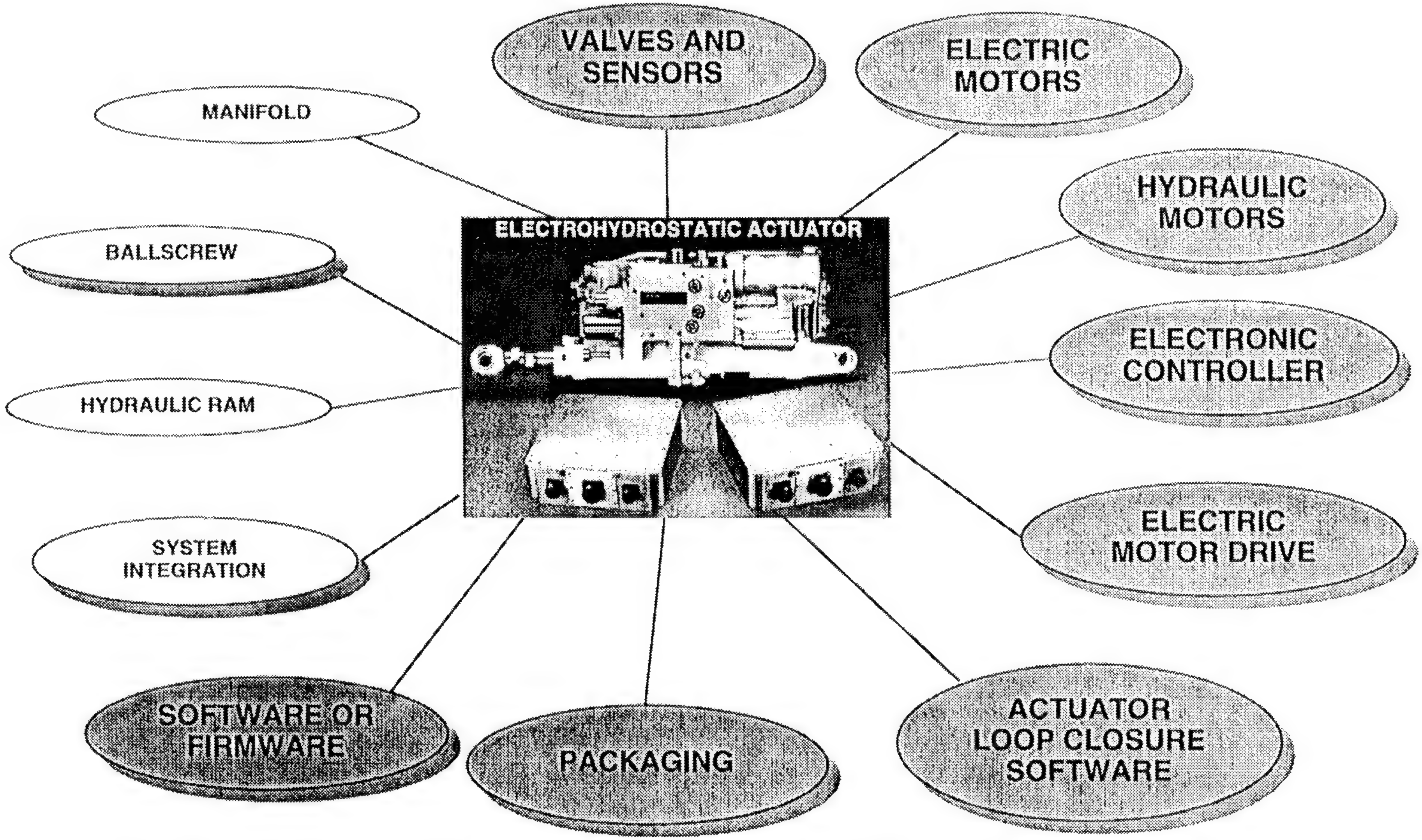
- Percent of total EHA system cost
- Components with high commonality with commercial technologies



PCC_97_0036_ 29

Electric Actuation Systems Have Greater Commonality With Developing Commercial Technologies

BOEING



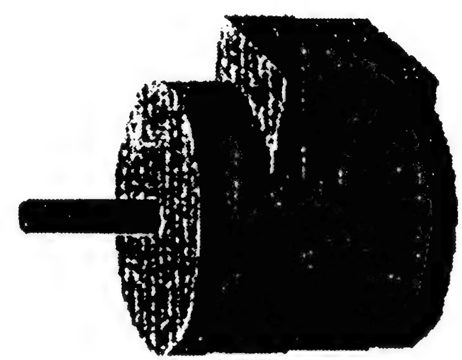
PCC_97_0036_ 18

"Smart" Actuators

High Temperature Electronics Enable Integration Of Control Electronics With Actuator In Harsh Environment

Benefits:

- Ease of installation
- Ease of maintenance
- Distributed fault-tolerant control
- Lower production cost
- Reduce cabling problems
- Space / weight savings



Rockwell Science Center

PPC-97-0005-027

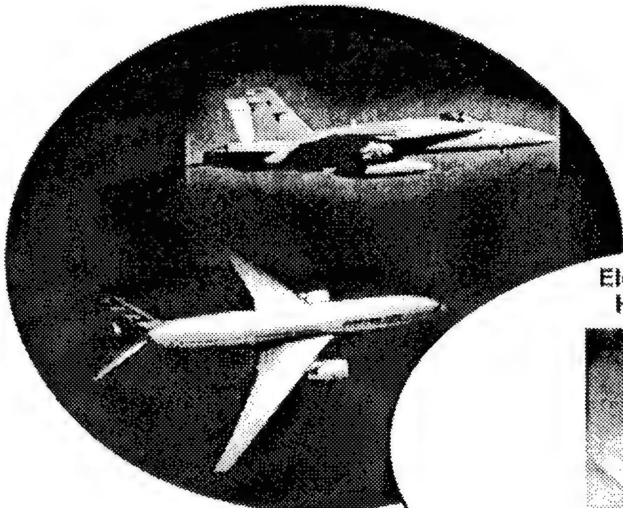
Boeing North American, Inc.
North American Aircraft Division
PROPRIETARY DATA

Electrically Powered Hydraulic System (EPHS)

BOEING

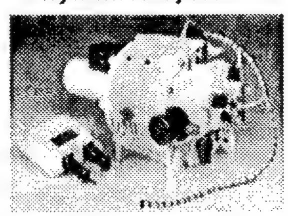
Dual Use of EPHS Technology

Military/Commercial Aircraft



Benefits
- 200-300% reliability improvement
- 20-30% reduction in installation time
- 20-25% reduction in cost
- 10-20% overall system weight savings
- 2-4% fuel savings
- 5-10% life cycle cost savings
- Simplified field maintenance

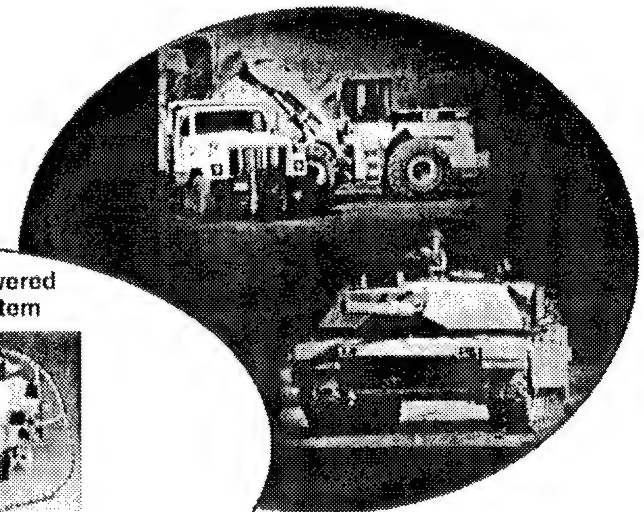
Electrically Powered Hydraulic System



Controller	Motor Drive	Motor/Pump

Supports other applications
- Electromechanical actuation
- Electrohydrostatic actuation
- Air conditioning system
- Radiator fan
- Oil cooling pumps
- Auxiliary motor pump

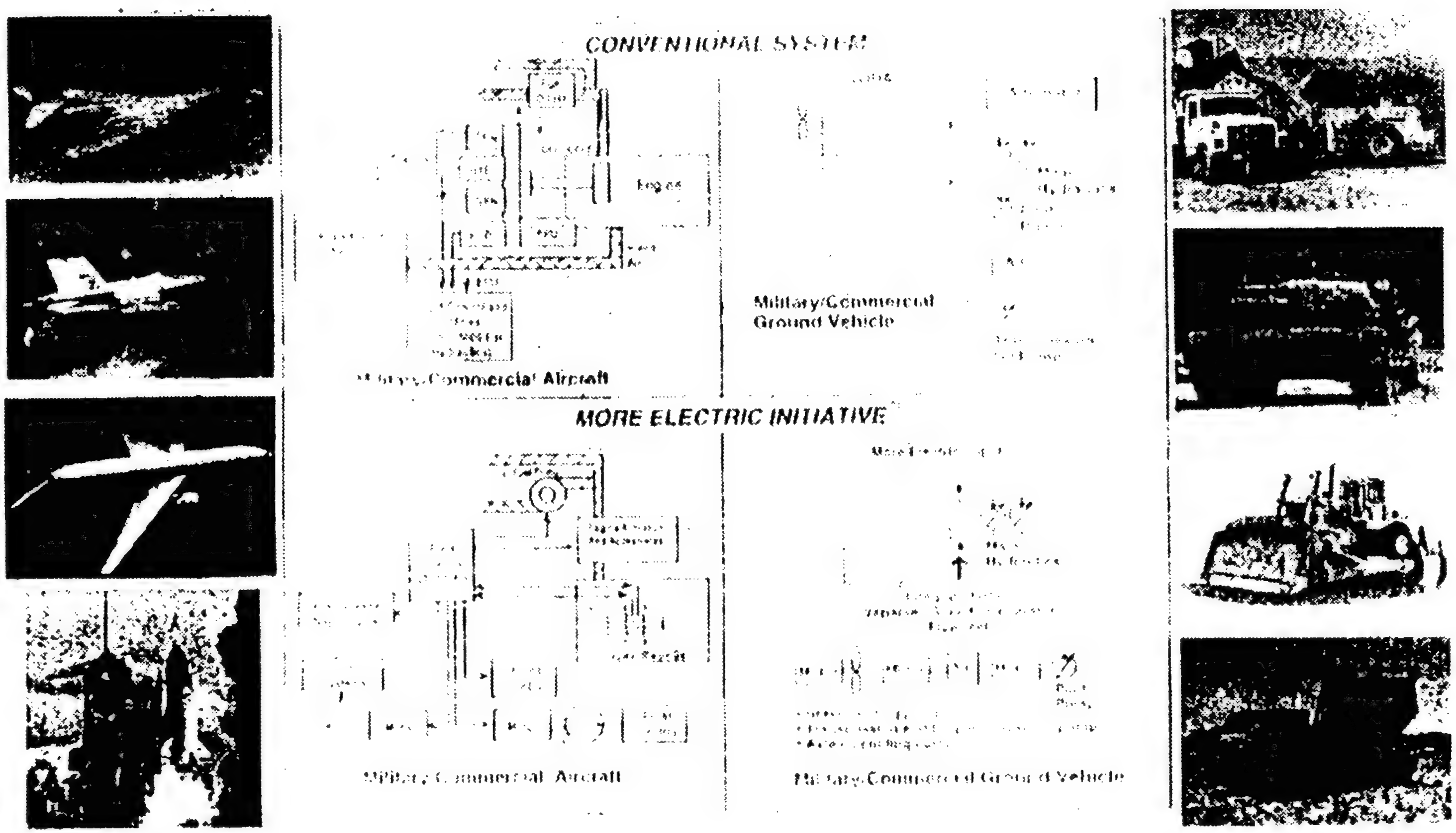
Commercial/Military Ground Vehicles



Benefits
- 5% fuel savings
- 5% productivity increase
- No overall vehicle cost increase
- Reduced operating cost

EPHS-97-0025

Electrically Powered Hydraulic System



Electrically Powered Hydraulic System Program

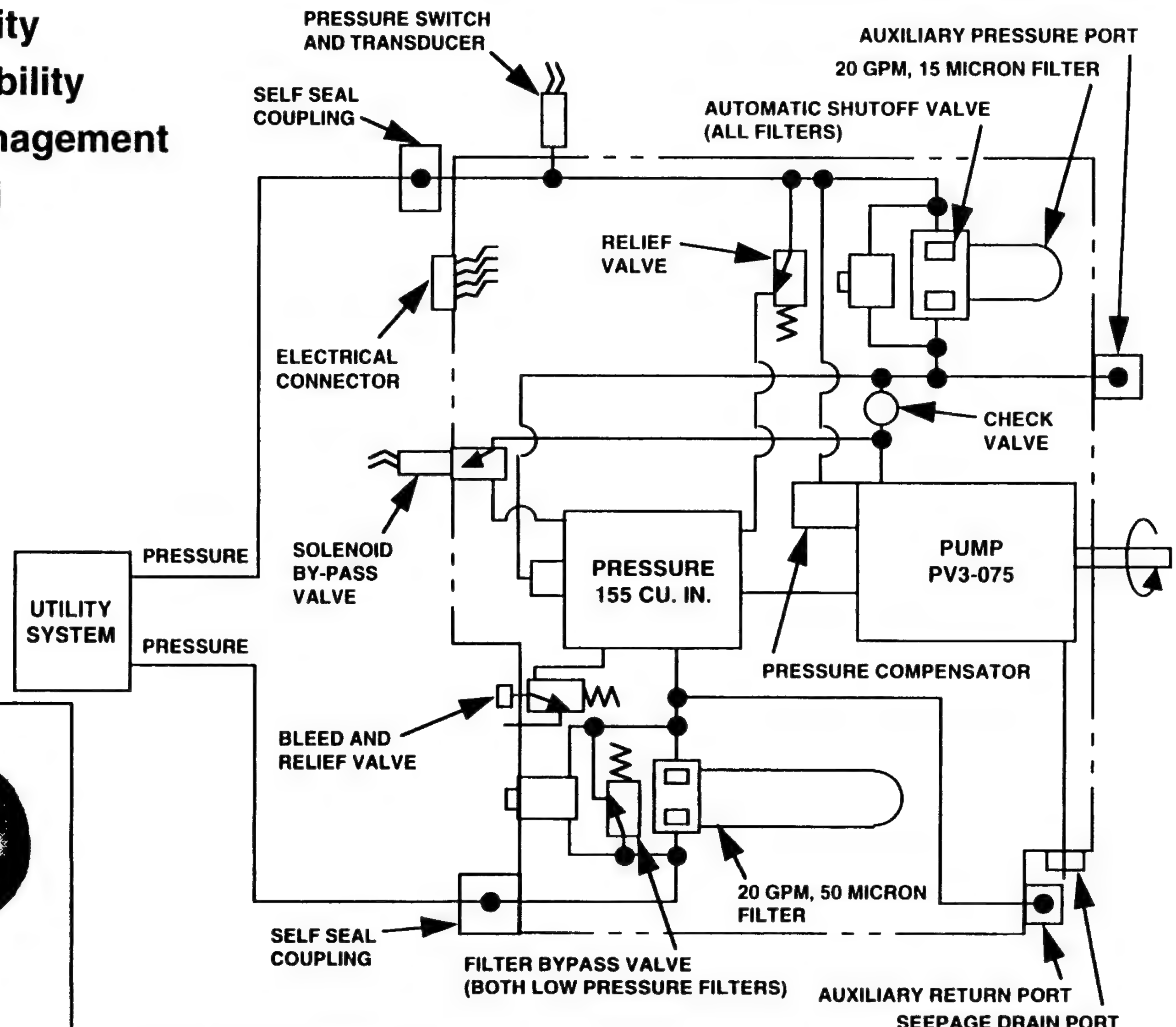
BOEING

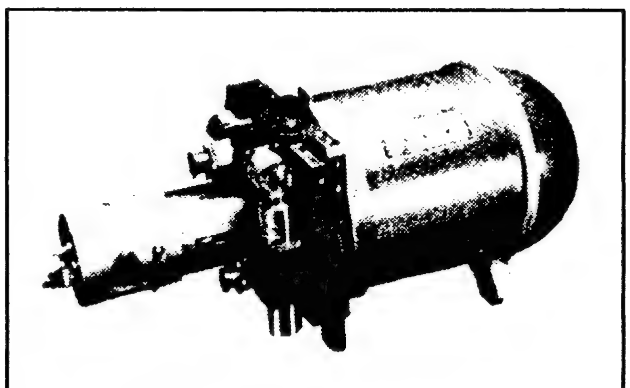
- Goal
  - Design, develop and fabricate a dual-use, high temperature, fault tolerant electrically powered hydraulic system for military and commercial aircraft and commrcial ground vehicles
- Team
  - Boeing, Rockwell Science Center, Vickers, Caterpillar
- Program value and schedule
  - $4.88 million (50% DARPA matching)
  - 18 months
- Key technologies
  - Flight worthy switched reluctance electric motor
  - 90°C fault tolerant switched reluctance motor drive and controller
  - Hydraulic pump and electric motor integration
  - On-line diagnostics

PCC_97_0036_ 35

Our Motor / Motor Drive Technology Is Applicable Is Zone Hydraulic

- Provide better power density
- Provide fault tolerant capability
- Provide better thermal management
- Integrate more commercial technologies

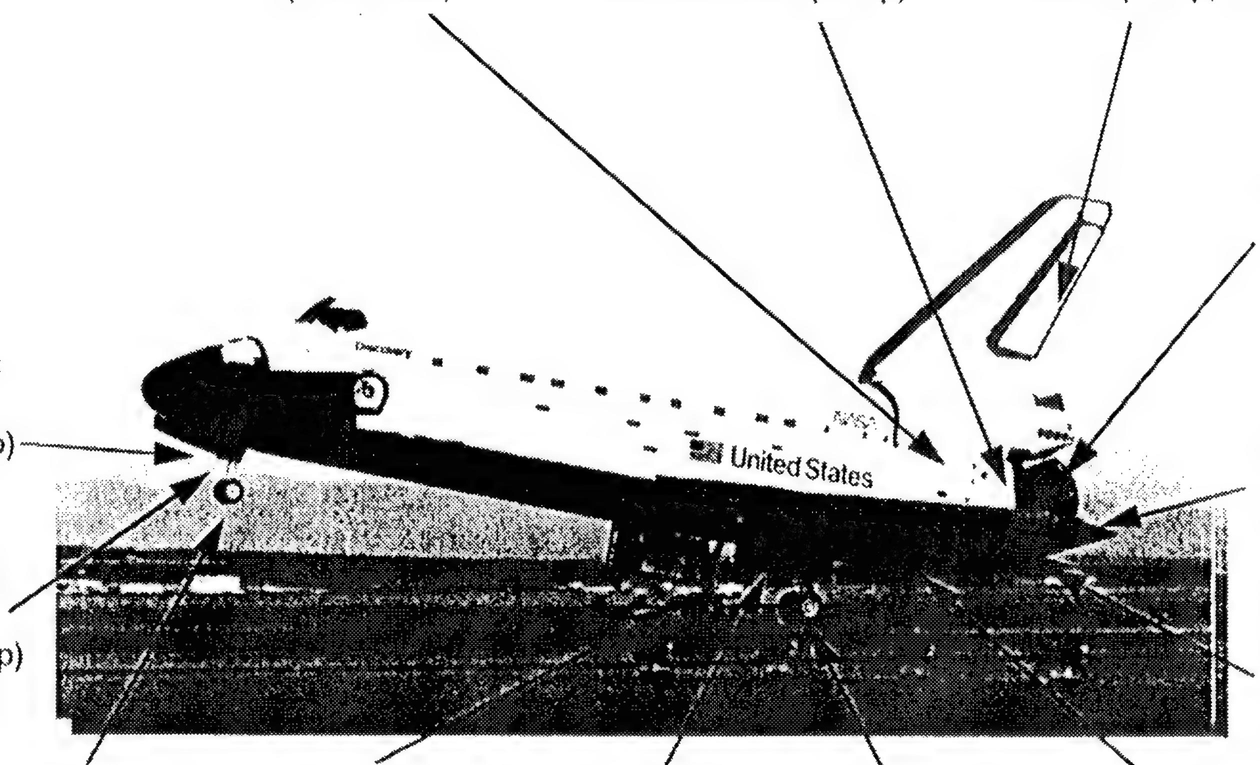




PPC-97-0005-012

Boeing North American, Inc.
North American Aircraft Division
PROPRIETARY DATA

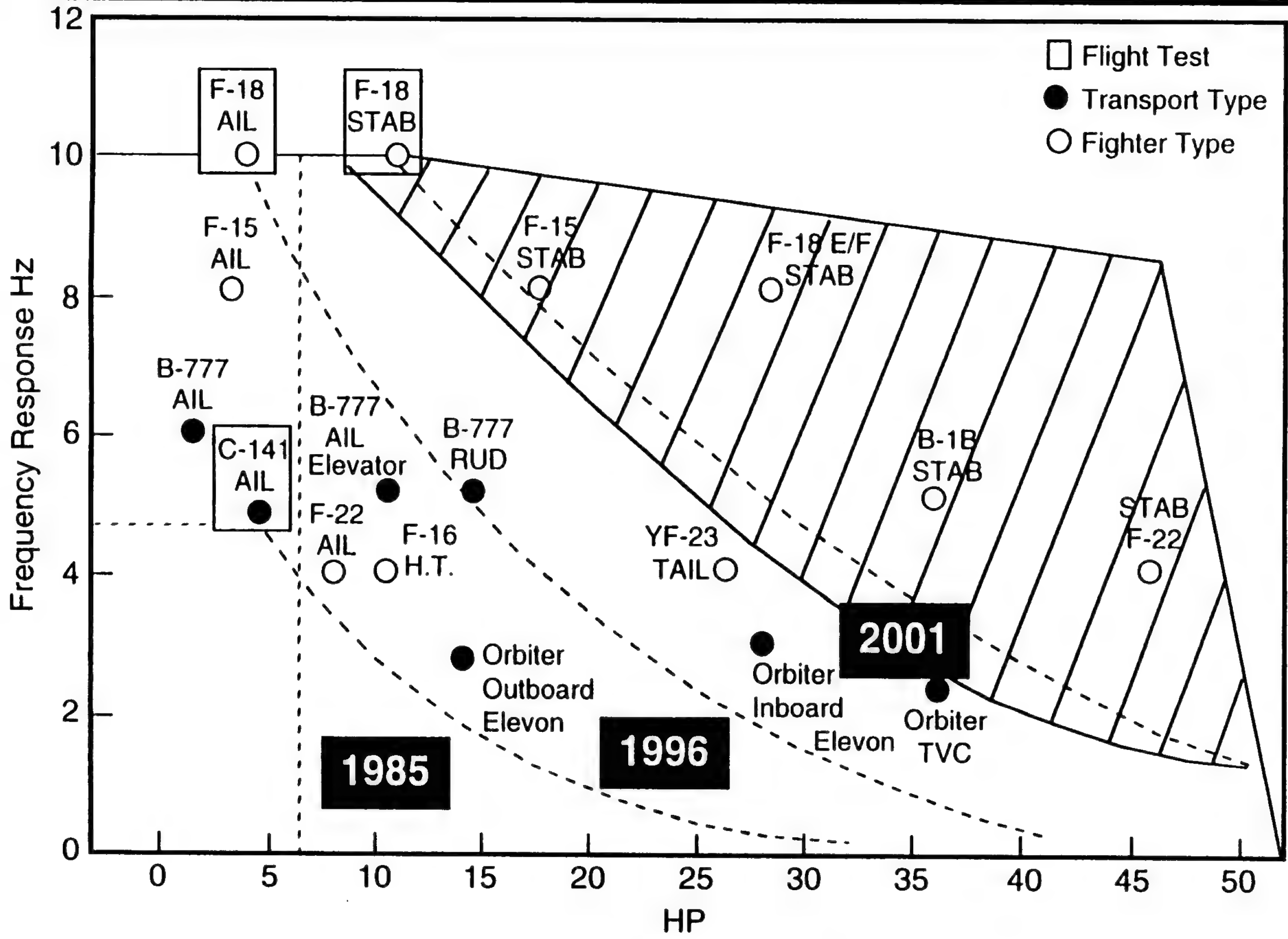
Target Electric Actuation Applications to the Orbiter



PPC_97_0026-015

BOEING PROPRIETARY DATA

Electric Actuation Technology is Available to Support Most Aircraft Requirements



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BOEING PROPRIETARY DATA

PPC_97_0013

Possible Impact Of Electric Actuation On Fighter / Attack Aircraft

- 10 - 20% system weight (preliminary studies)
- 25% reduction in cost (goal)
- Reliability and maintainability (studies in progress)
- Related programs
  - J / IST
  - F-16 studies
  - F-18 studies

Hydraulic Fluids and Seals Workshop

Air Force Research Laboratory
Materials Directorate

Hydraulic System's Future

Glenn Anderson
The Boeing Company
McDonnell Aircraft and Missile Systems

17-18 March 1998 **The Boeing Company**

Introduction

- Future of Hydraulics is Bright
- All Aircraft Use Hydraulic Flight Controls and Utilities
- Expect Hydraulic Technology To Be With Us Well Into Next Century
- Still The Most Capable Technology
- Full Potential Still Not Reached

Current State of the Art

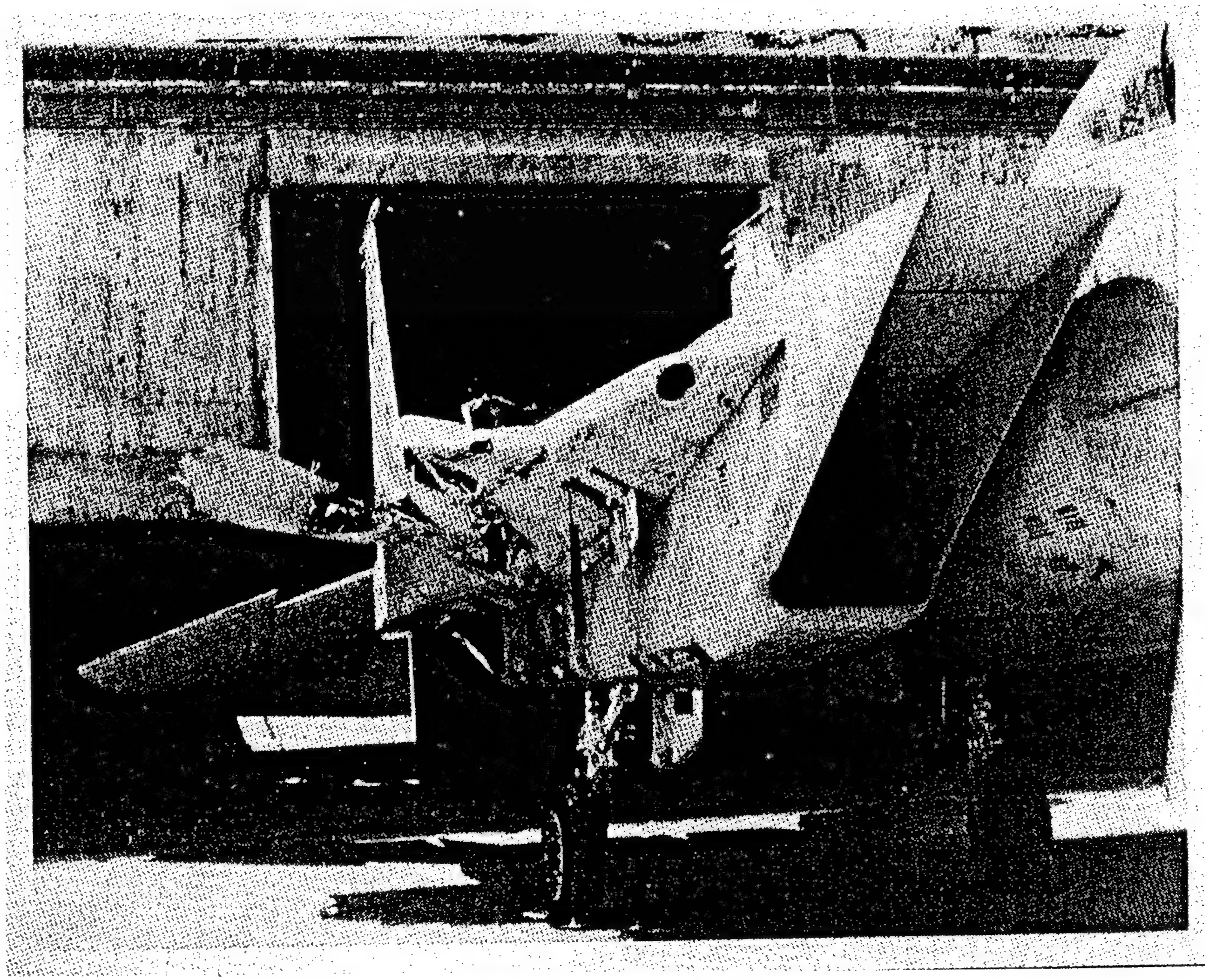
- Pressure Beyond 3000 PSI in Production
- 4000 PSI for B-1, C-17, B-2, F-22
- Variable Pressure for F-18 E/F
  - 5000 PSI for Peak Loads
  - 3000 PSI Steady State
- 5000 PSI on V-22

Current State of Art

- Improved Tubing and Fittings
  - Titanium Tubes
  - Swage and Welded Fittings
- Improved Seals
  - Significant Reduction in Leakage
- Improved Fluids
  - Fire Resistance Fluids in Use
    - Mil-H-83282 and Mil-H-87257
  - Non-Flammable Fluids Available

- Direct Drive Valves in Flight Controls
  - Reduced Complexity
  - Reduced Waste Energy
  - Improved Reliability
- Fault Detection and Isolation
  - Reservoir Level Sensing
  - Switching Valves

Hydraulic Survivability



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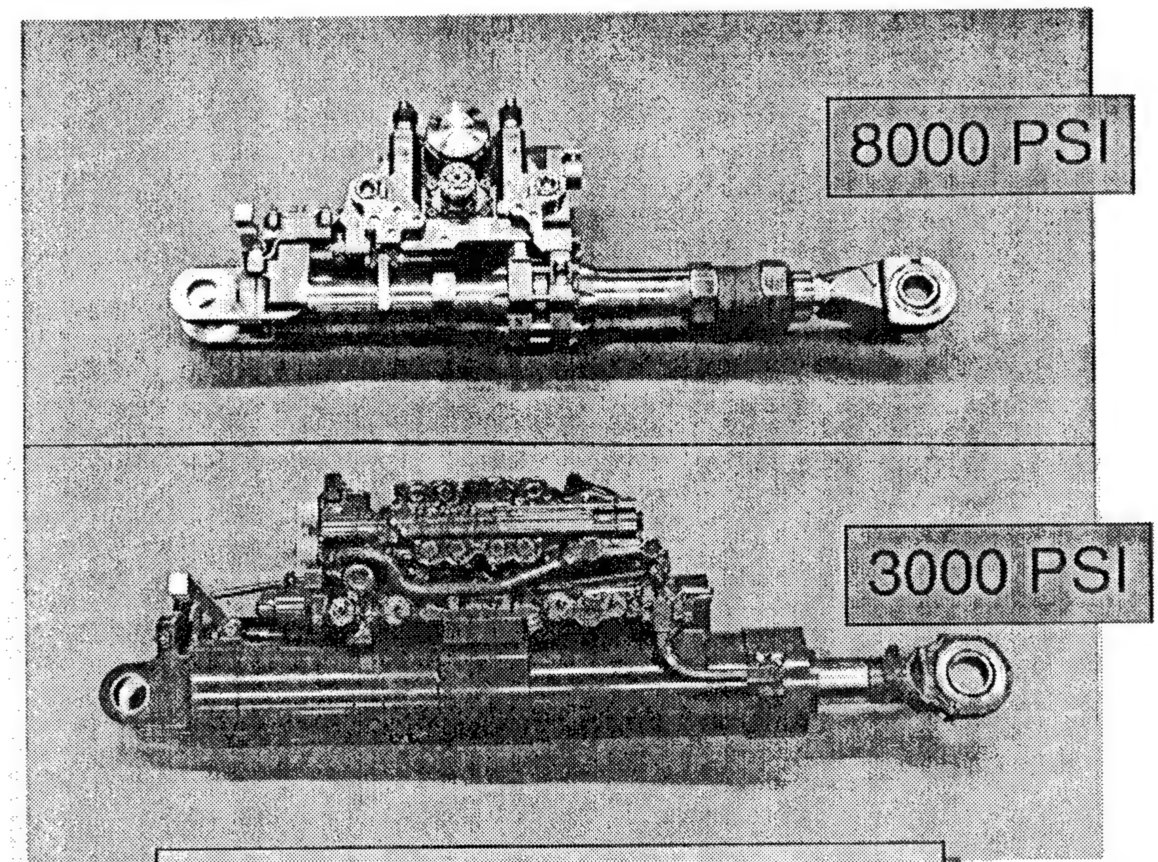
F-18 E/F Hydraulic System

- Modification to Existing Design
- 5000 PSI Capability Added to Reduce Volume and Weight
- Variable Pressure to Reduce Heat Rejection and Power Extraction
- Direct Drive Valves
- Welded and Ryngloc Fittings Used
- Integrate Product Teams with Customer and Supplier

High Pressure Technology



F15 Fly-By-Wire Stabilator

17-18 March 1998 The Boeing Company

High Pressure Technology

- System Weight Reduction of 20%
- System Volume Reduction of 40%
- Actuator Stiffness NOT Limiting
  - Enhanced Stiffness Demonstrated
  - Avoids Stiffness Sized Actuation
  - 250% Improvement Demonstrated

Future Needs
Continuous Improvement

- Develop Future Goals for Hydraulic Design
  - Reliability, Diagnostics, Performance
- Improved Subsystem Integration
  - Thermal and Power Management
  - Life Cycle Cost, Weight and Volume
- Increased System Level Diagnostics
  - Health Monitoring and Prognostics
- Why Do (Should) Seals Fail?
- Improved Surface Finishes and Processes

Future Needs

- Next Generation Fluids
  - Environmentally “Friendly”
  - Improved Seal/Fluid Combinations
  - High Temperature
  - Non-Flammable
- Reduced Weight and Volume of Components
  - High Speed Pumps
  - Higher Pressures
  -

Future Needs

- Improved HYTRAN Program
  - Originally Developed by USAF-WL
    - Fortran Program Language
  - Need PC Based Program, Windows Environment
- CAD Parametric Actuator Design
  - Standardization
  - Reduced Cost of Design, Qualification and Maintenance

Summary

Hydraulics is Available and Capable

Continuous Improvement Program Needed

Improvements Achieved Economically

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C-135 Testing and Transition

Briefer - Pat Donahay
Hydraulic System Engineer
C/KC-135 System Program Office
Tinker AFB OK

Phone (405) 736-3832

e-mail pjdonaha@po31.tinker.af.mil

C-135 Testing

- 33 FLTS Flight Test @ Grand Forks AFB
- Drained/Flushed both systems
- Achieved 92% & 93% MIL-H-87257
- Each System about 22 gallons capacity
- Took 110 gallons MIL-H-87257 to flush/refill

C-135 Testing

- Monitored by 33 FLTS for 1 year
- 275 flight hours
- EFAS self test failures in cold temperatures
- Same problem occurs with MIL-H-5606
- No evidence of varnish contamination
- No abnormal component failures
- Fluid appeared acceptable for C-135 use

C-135 Service Test

- 25 KC-135 A/C at 4 bases
- Drained reservoirs & opened lines
- Achieved 25% - 50% MIL-H-87257
- Significant lesson learned
- Rapid intro of -87257 may cause older components to leak immediately
- Gradual intro of fluid preferable

C-135 Conversion

- May 96 - OC-ALC sent message to -135 users to order MIL-H-87257
- Existing -5606 supplies may be consumed
- Begin topping of with MIL-H-87257
- Conversion proceeding slowly due to large base supply of -5606 and initial unavailability & high cost of -87257

C-135 Conversion Summary

- Some increase in leaks expected due to compression set in older components
- Leaks minimized if fluid introduced gradually
- Problems are minor given benefits of reduced fire hazard
- Estimate 5 years to obtain 90% MIL-H-87257

SEAL TESTING

ALAN FLETCHER

AFRL/MLSE

SEAL TESTING FOR MIL-H-87257

HYDRAULIC FLUIDS AND SEALS WORKSHOP

ALAN J. FLETCHER

17 MARCH 1998

SEAL TESTING

ALAN FLETCHER — AFRL/MLSE

TESTING OVERVIEW

- GOAL
  - TEST STATIC AND DYNAMIC SEAL COMPATIBILITY WITH MIL-H-87257
- TEST PLAN
  - COMPARISON TESTING WITH MIL-H-5606 AND MIL-H-83282
    - PHYSICAL PROPERTIES
    - STATIC SEALS
    - DYNAMIC SEALS

SEAL TESTING

ALAN FLETCHER AFRL/MLSE

- MIL-H-87257 FLUIDS
  - ROYCO 777
  - BRAYCO MLO-96-102
- MIL-H-83282 FLUIDS
  - TECHNOLUBE MLO 87-163
- MIL-H-5606 FLUIDS
  - BRAYCO
  - BLEND

SEAL TESTING

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- SEALS
  - NITRILE MIL-P-25732
  - NITRILE MIL-P-83461
  - FLUOROCARBON MIL-R-83248
  - FLUOROCARBON MIL-R-83485
  - HNBR

SEAL TESTING

ALAN FLETCHER — AFRL/MLSE

- PHYSICAL PROPERTIES
  - SWELL
  - COMPRESSION SET
  - TENSILE
  - ELONGATION
  - MODULUS
  - HARDNESS

SEAL TESTING

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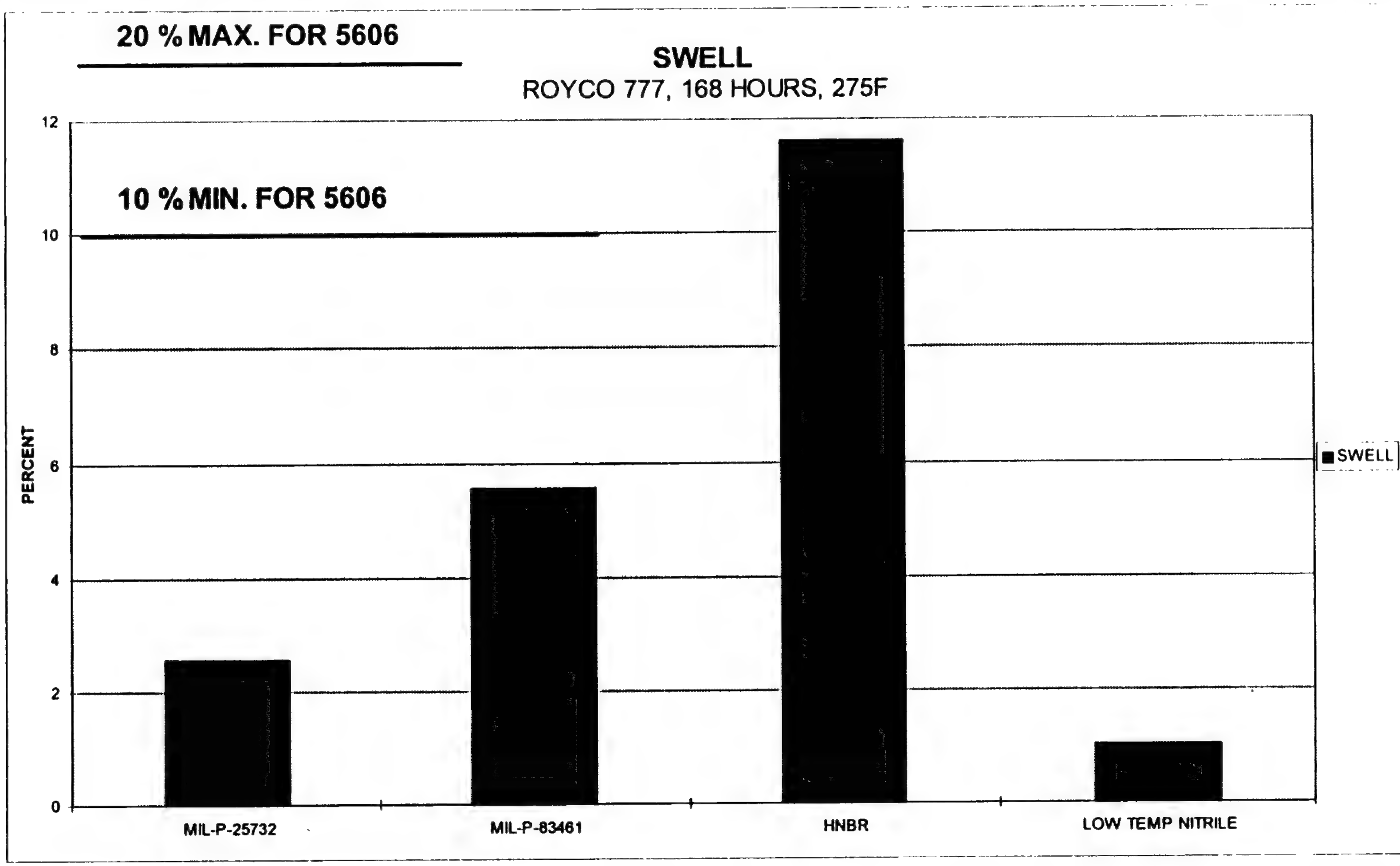

SEAL TESTING

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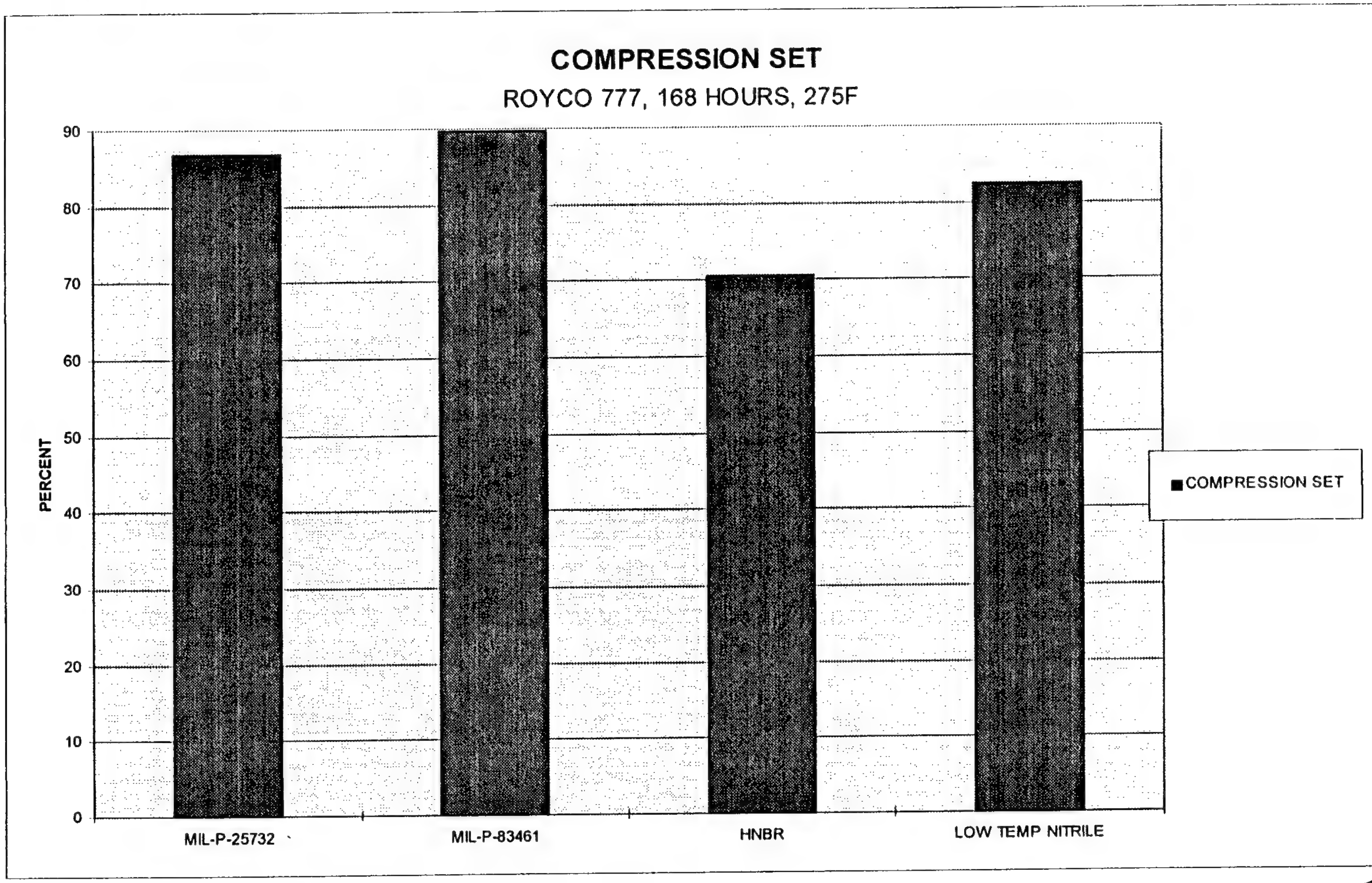

SEAL TESTING

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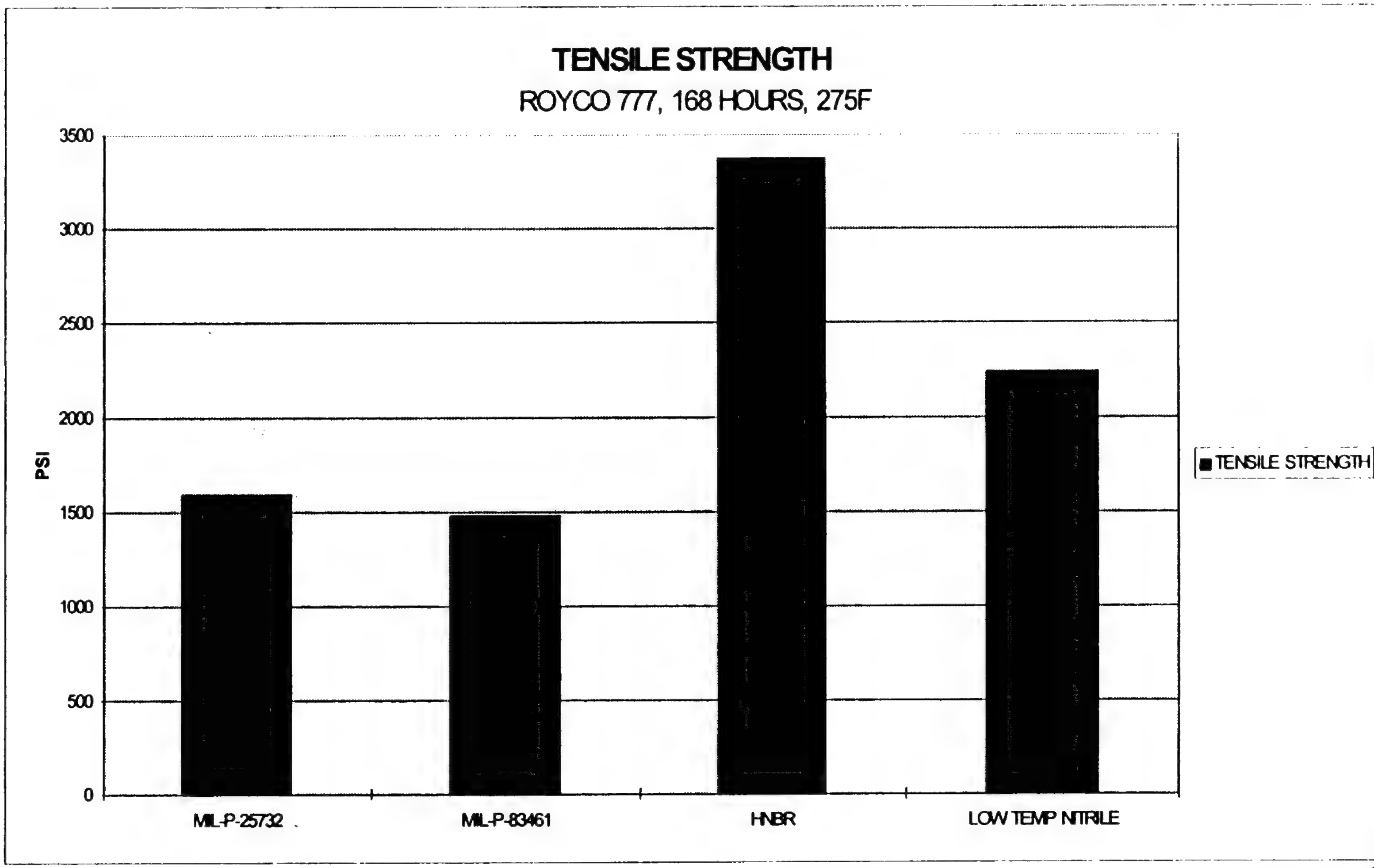

SLIDE 8

SEAL TESTING

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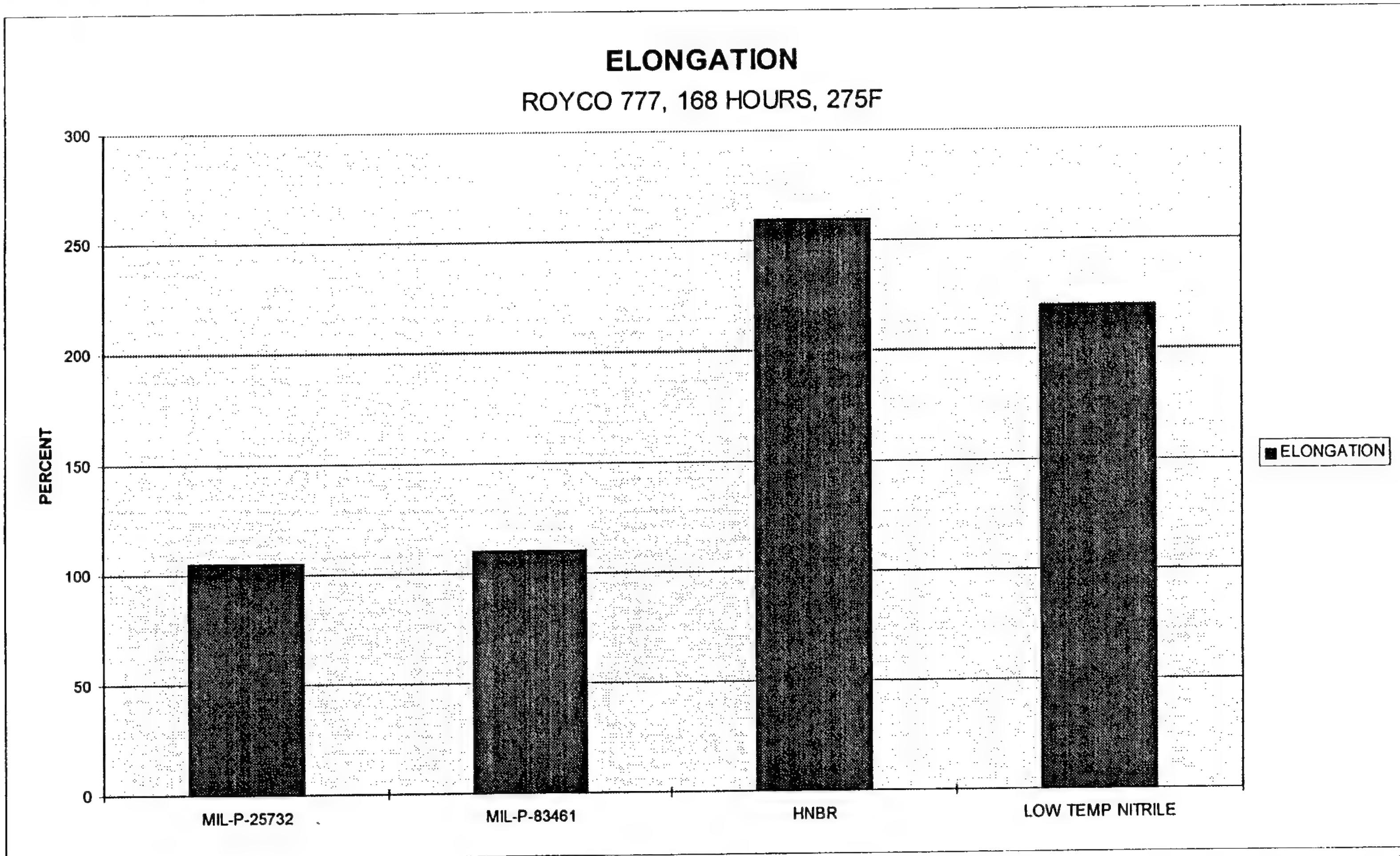

SEAL TESTING

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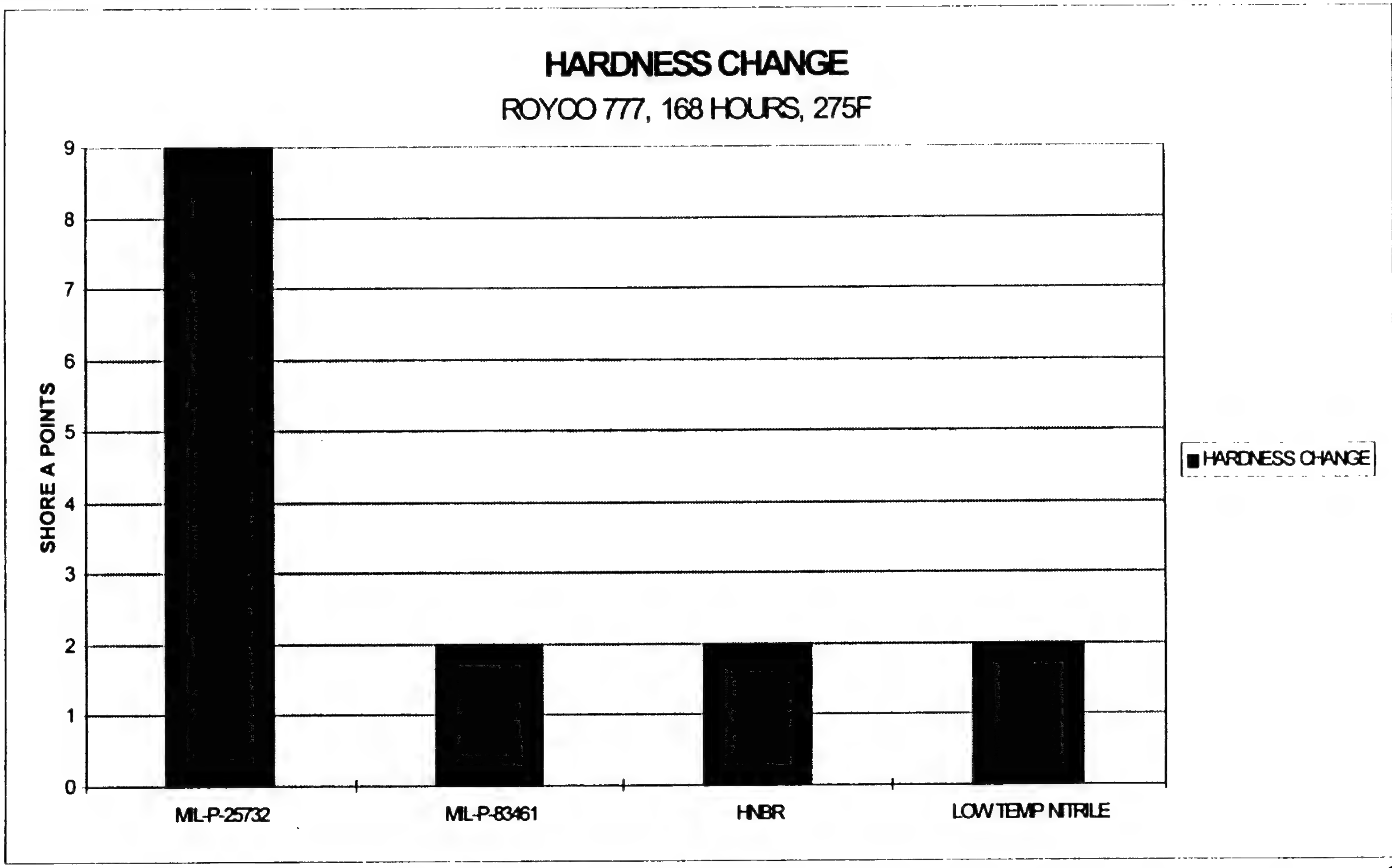

SEAL TESTING

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STATIC SEAL TESTING

- INITIAL AGING
  - 4000 PSI, 72 HOURS, 275F
- IMPULSE TESTING AT VARIOUS TEMPS.
  - -65F, -40F, -20F, 73F, 275F
- FOUR CONTINOUS PHASES
  - IN MIL-H-5606
  - IN MIL-H- 83282
  - IN MIL-H- 87257
  - REPEAT IN MIL-H-83282

SEAL TESTING

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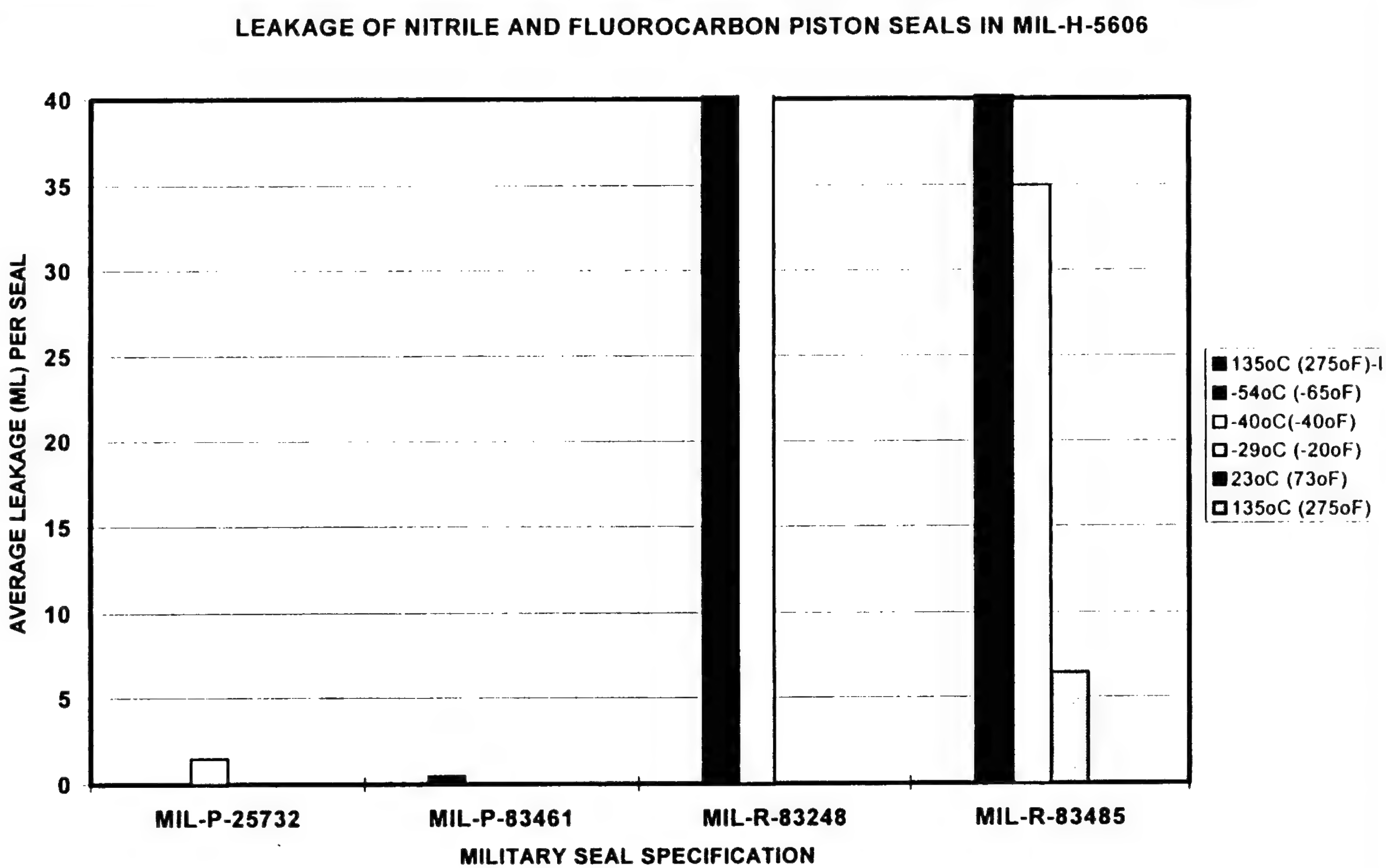

SEAL TESTING

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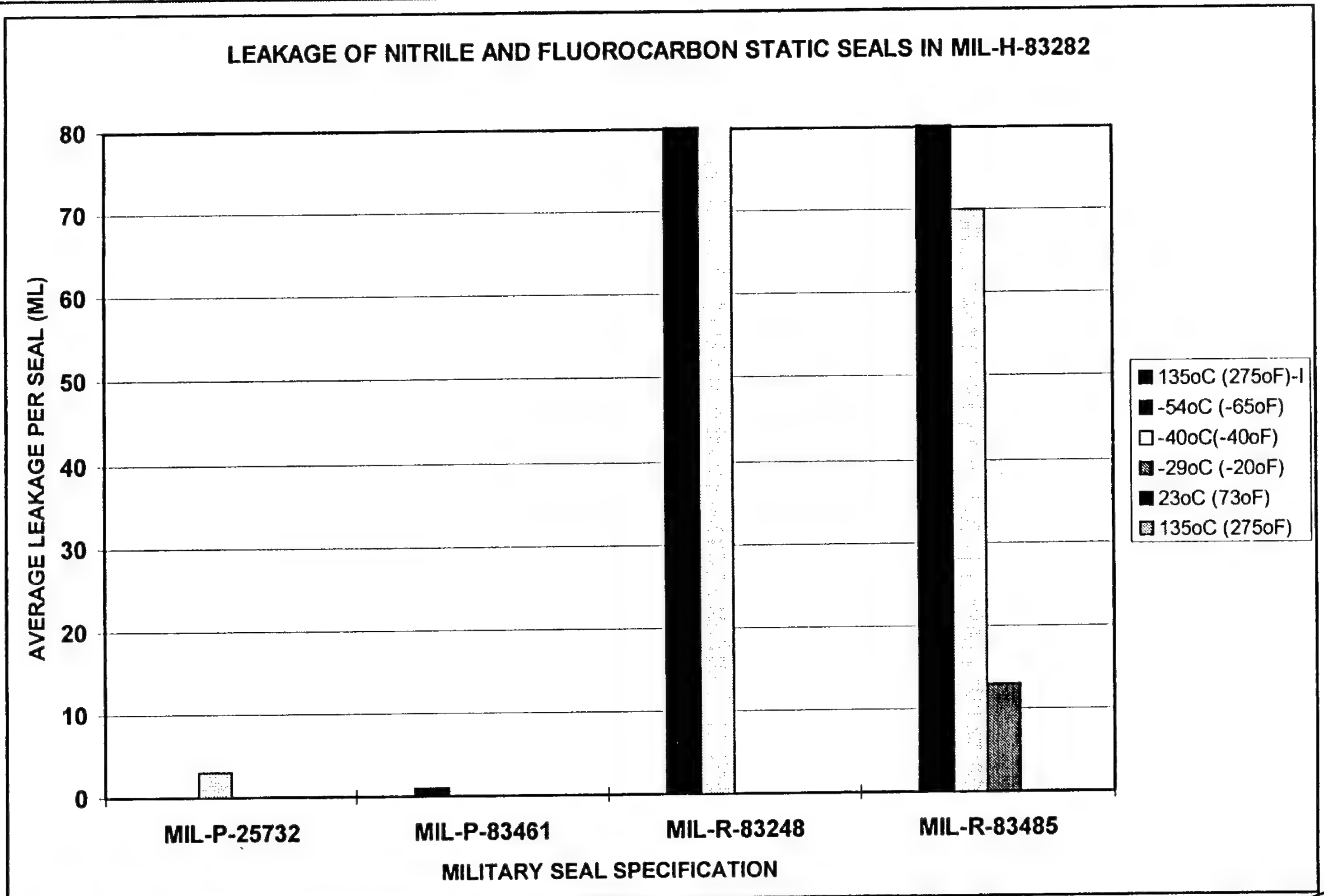

SEAL TESTING

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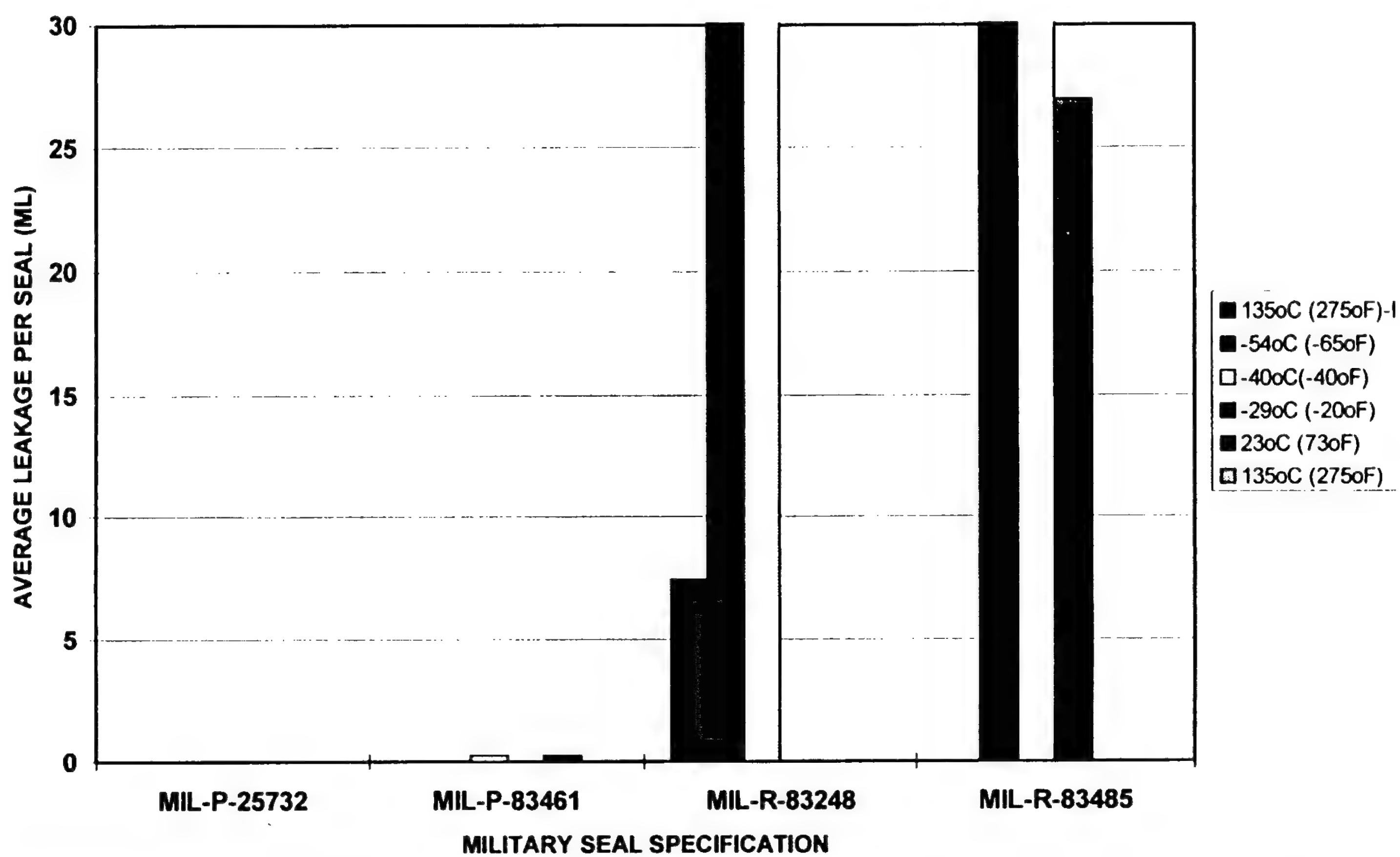
LEAKAGE OF NITRILE AND FLUOROCARBON STATIC SEALS IN MIL-H-87257



SEAL TESTING

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DYNAMIC SEAL TESTING

- CHEW TEST (1)
  - DITHER STROKE
  - 4000 PSI
  - 275F
  - LEAKAGE CHECKS AT -65F
  - ROYCO 777 MIL-H-87257
  - WITH BACKUP RINGS

SEAL TESTING

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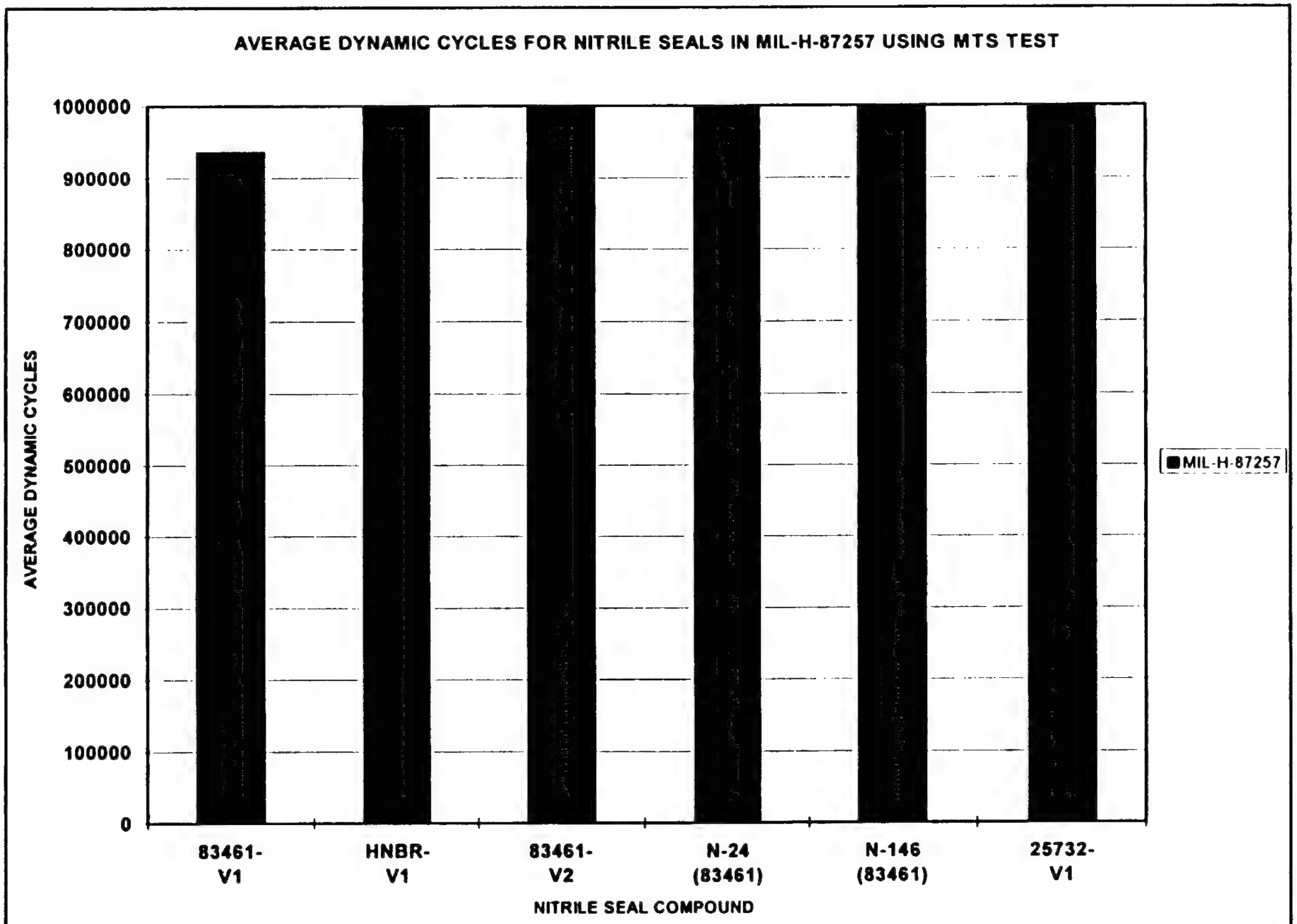

SEAL TESTING

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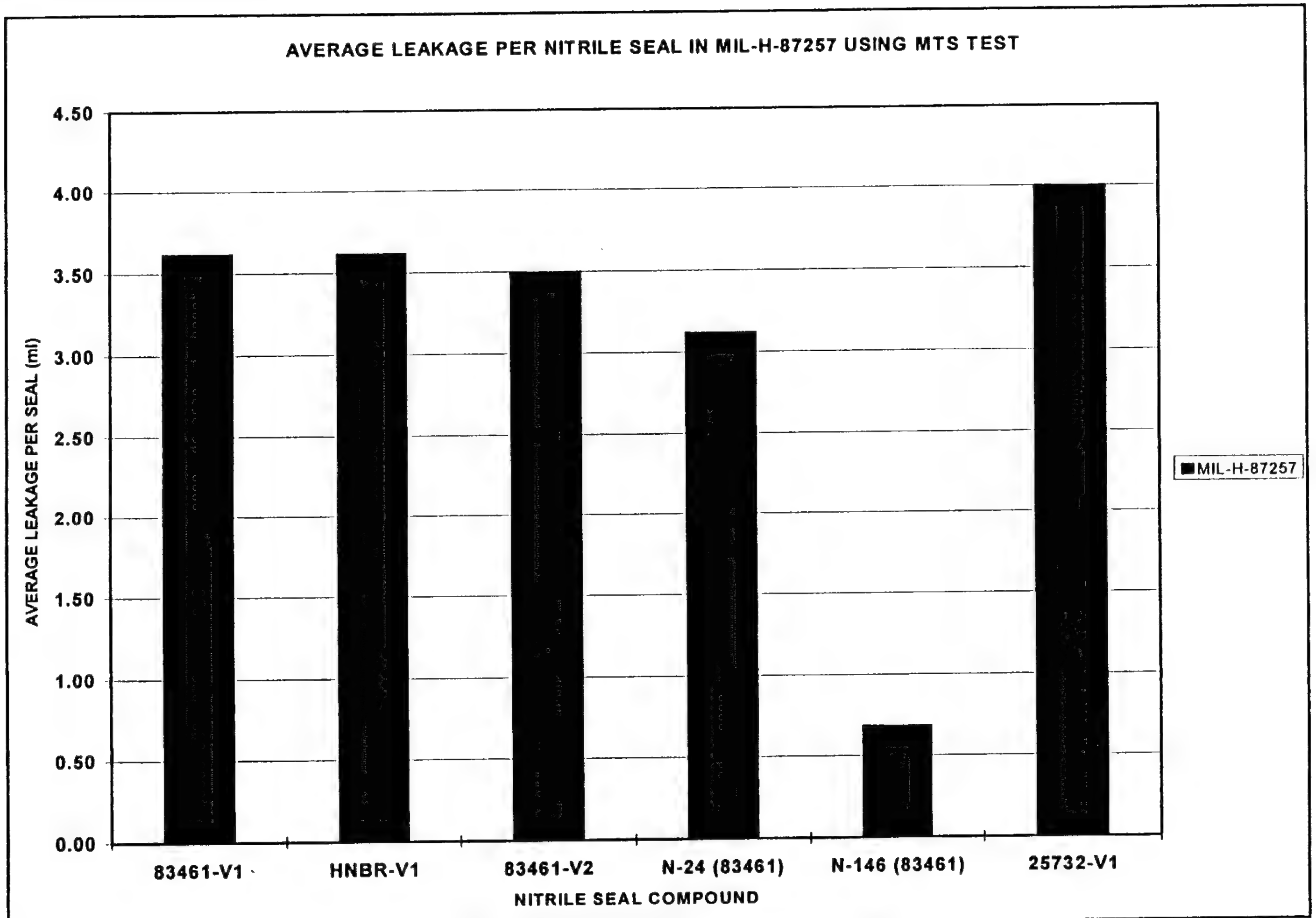

SEAL TESTING

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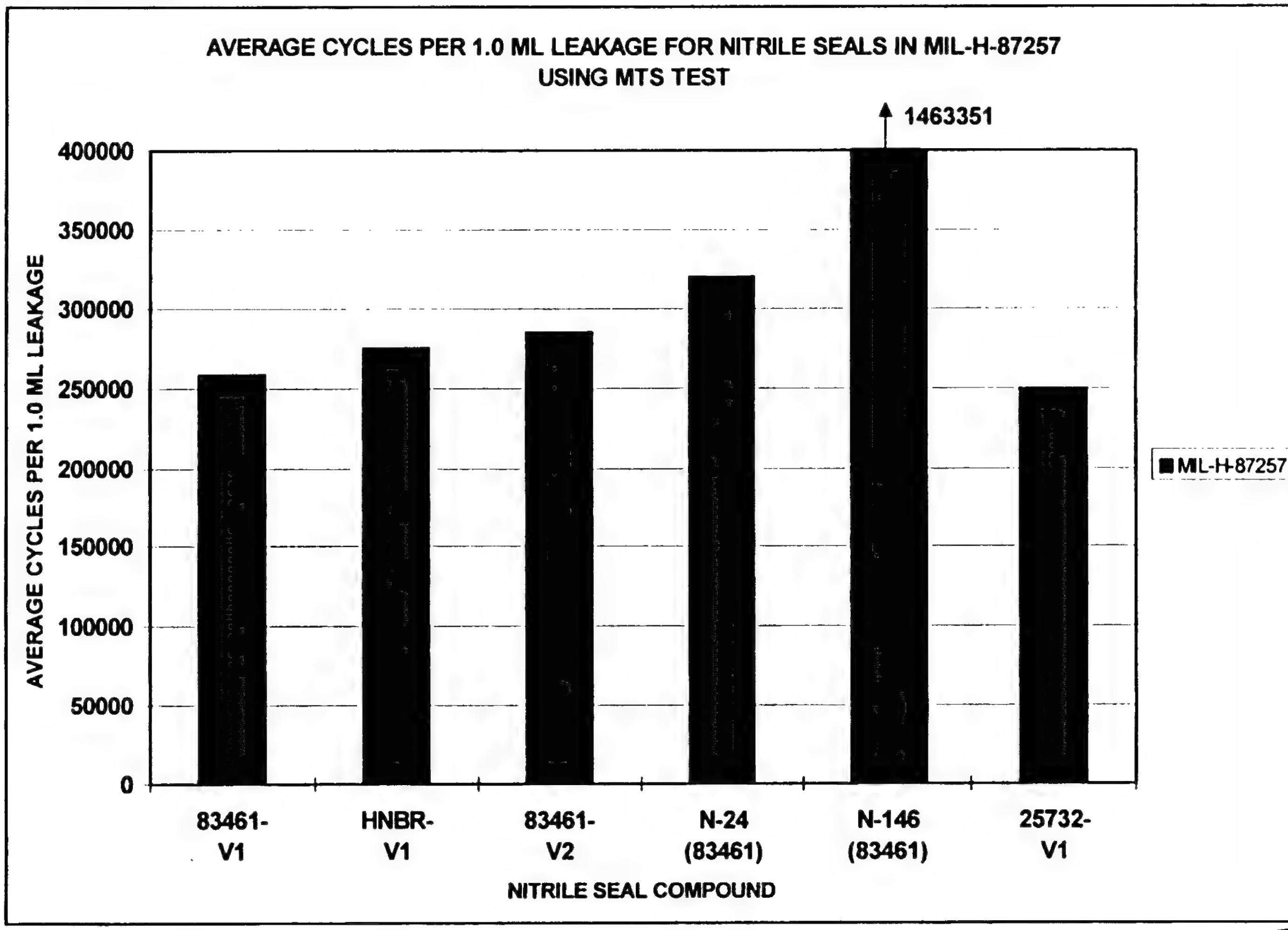

SEAL TESTING

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DYNAMIC SEAL TESTING

- CHEW TEST (2)
  - 2 INCH STROKE, 1 HZ
  - 3000 PSI, 275F
  - TECHNOLUBE MLO 87-163 MIL-H-83282
  - ROYCO 777 MIL-H-87257
  - BRAYCO MLO-96-102 MIL-H-87257
  - WITH BACKUP RINGS

SEAL TESTING

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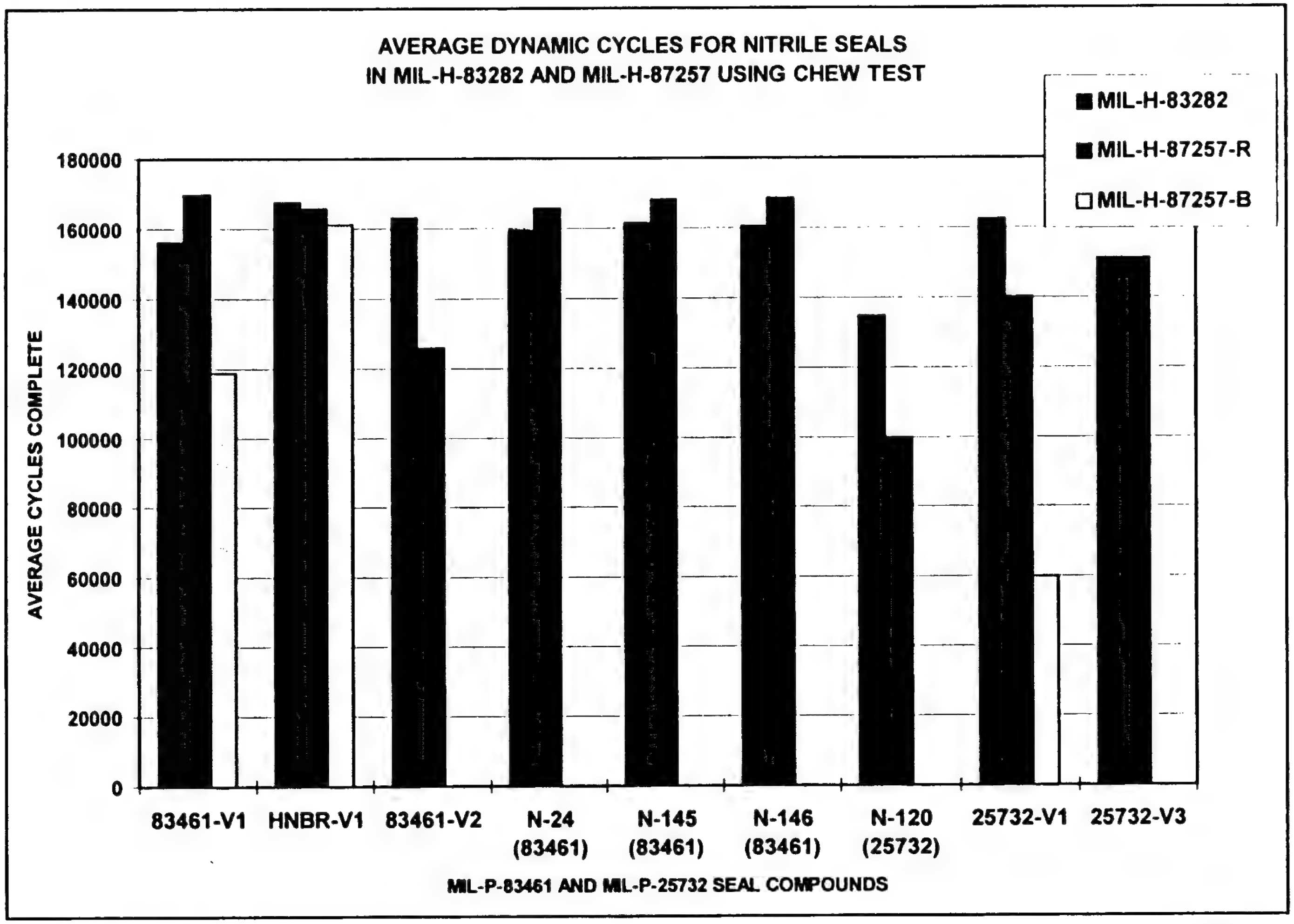

SEAL TESTING

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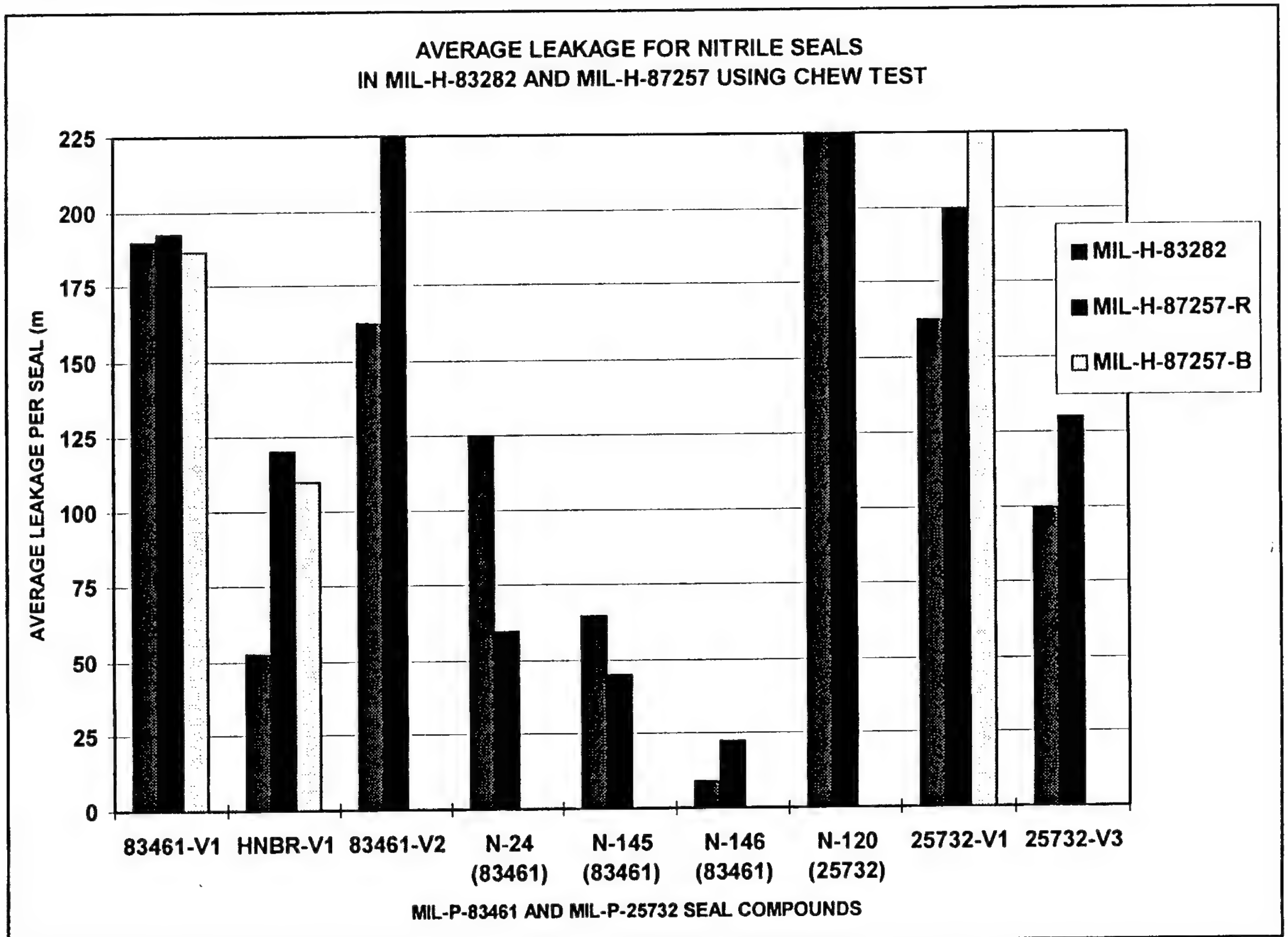

SEAL TESTING

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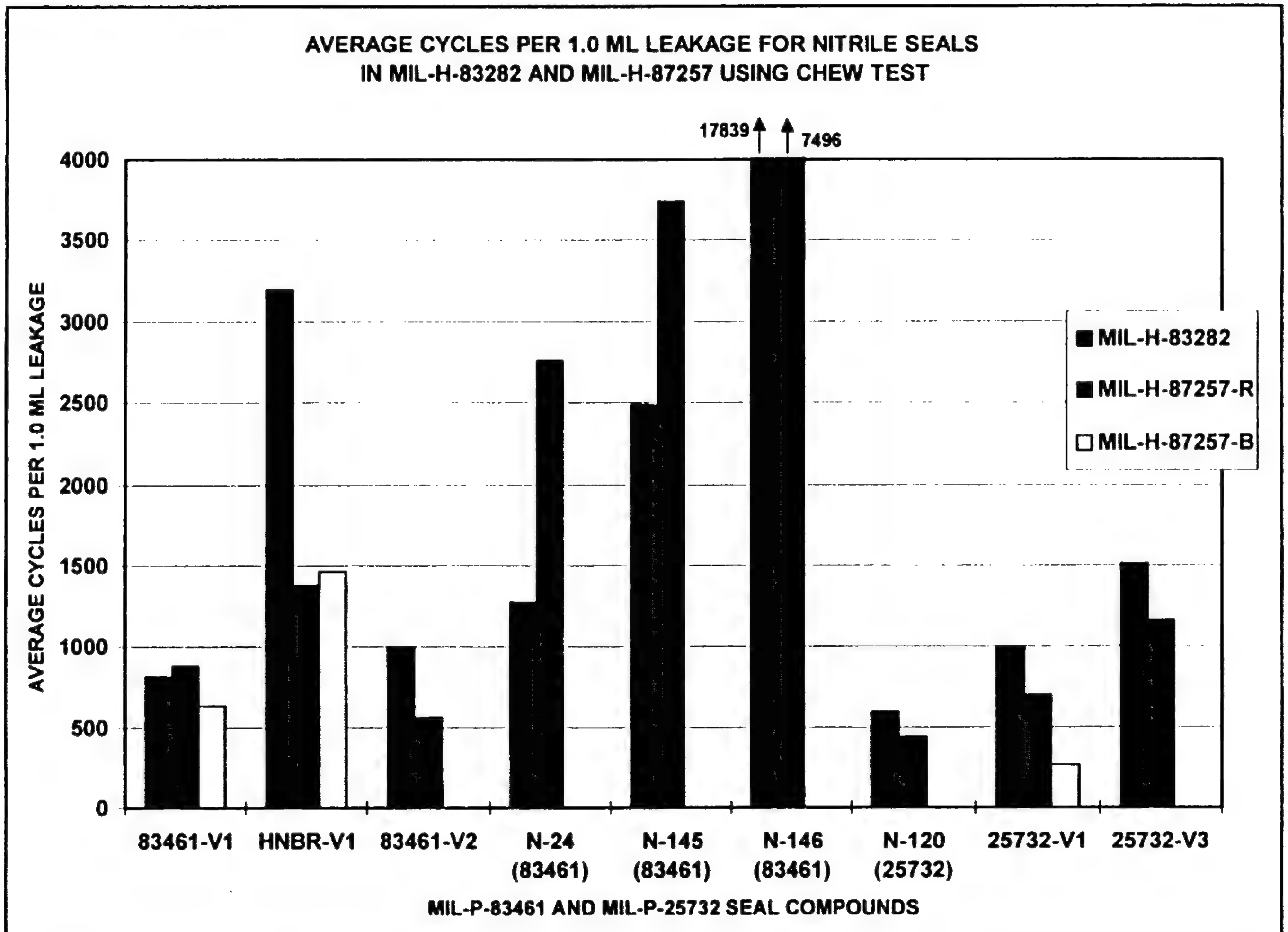

SEAL TESTING

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DYNAMIC SEAL TESTING

- ROD SEAL TEST
  - 4 INCH STROKE, 30 CYCLES/MIN
  - 1500 PSI, 275F
  - BLEND OF MIL-H-5606
  - BLEND OF MIL-H-83282
  - ROYCO 777 MIL-H-87257
  - WITHOUT BACKUP RINGS
  - WITH BACKUP RINGS

SEAL TESTING

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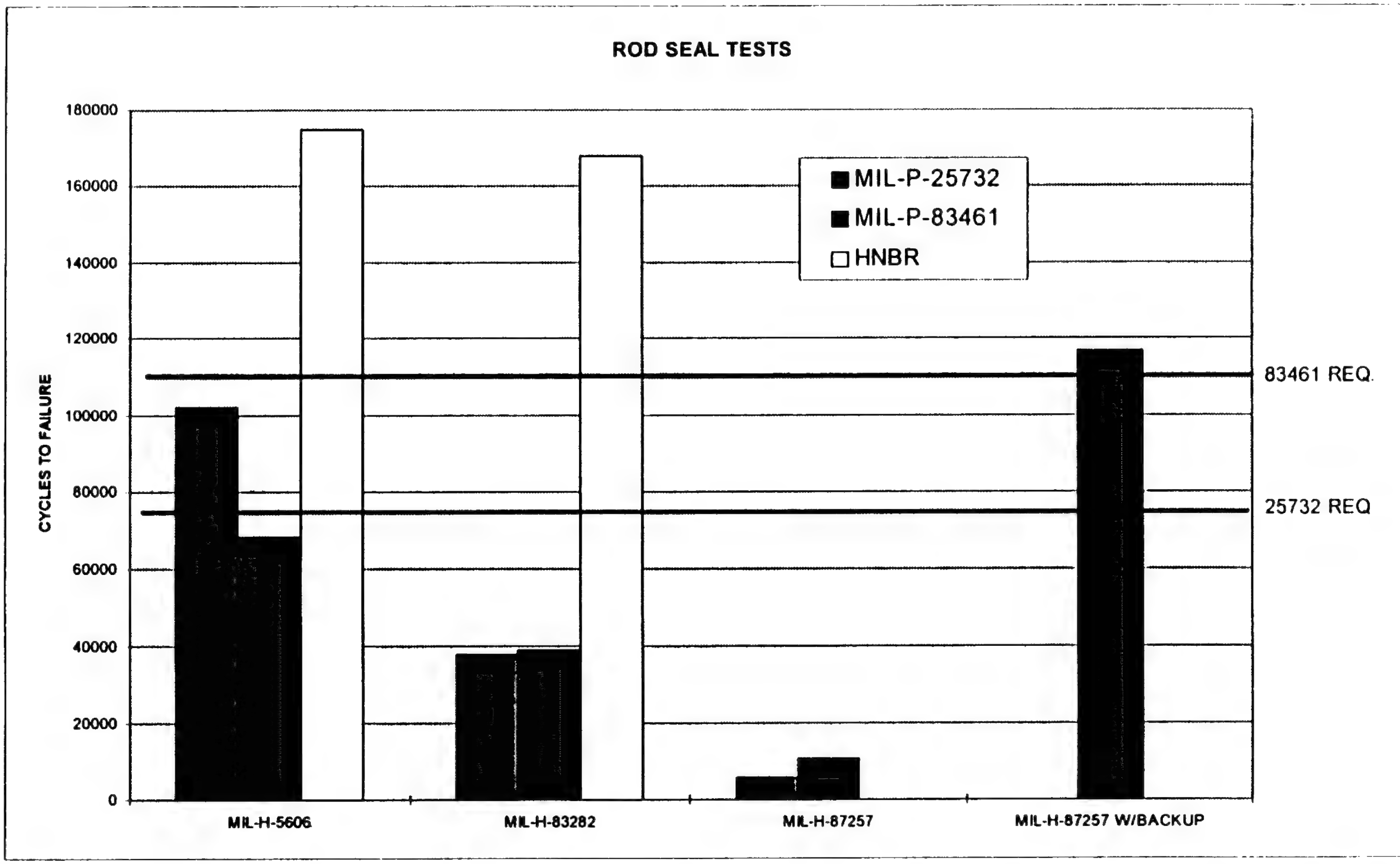

SEAL TESTING

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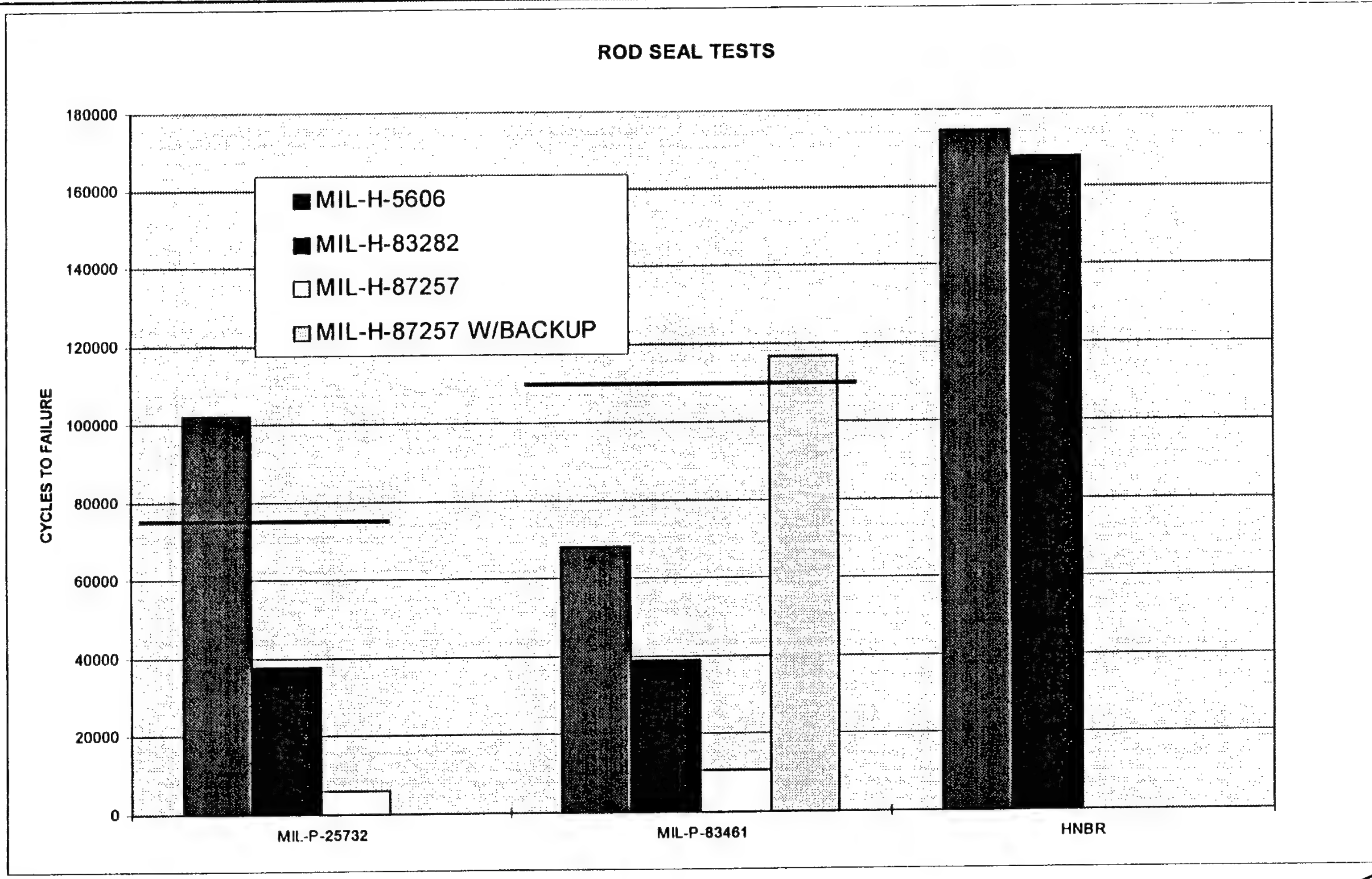


SEAL TESTING

ALAN FLETCHER AFRL/MLSE

CONCLUSIONS

- CONCERNS
  - – LOW VOLUME SWELL
  - – HIGH COMPRESSION SET
    - TEMPERATURE RELATED (275F)
  - – DYNAMIC SEAL LEAKAGE
    - WITHOUT BACKUP RINGS

SEAL TESTING

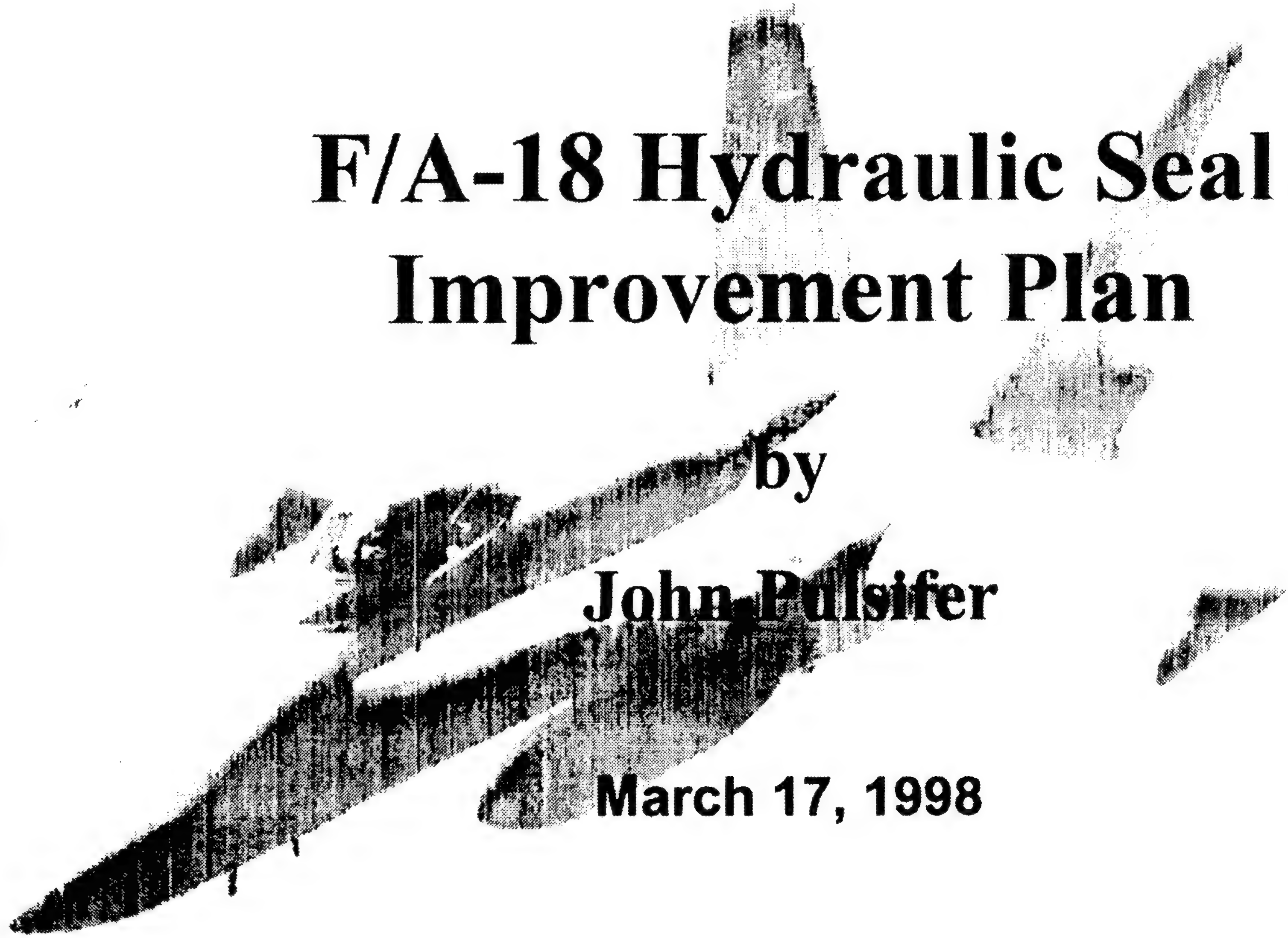
ALAN FLETCHER AFRL/MLSE

CONCLUSIONS

- RECOMMENDATIONS
  - REPLACE BY ATTRITION
    - VOLUME SWELL DIFFERENTIAL
  - RESEARCH YOUR SYSTEM FOR DYNAMIC SEALS WITHOUT BACK UP RINGS

PEO(T), F/A-18 IPT

TEAM HORNET



F/A-18 Hydraulic Seal Improvement Plan

by

John Pulsifer

March 17, 1998

F/A-18 Flight Control Servo Leakage

System Parameters

- Fluid: Mil-H-83282
- Pressure: 3000 psi
- Temp: -65 to 275 F

Primary Flight Control Actuation

- Dual System Servocylinders: Horizontal Stabilator (tandem) and TEF (parallel)
- Single System Servocylinders: Aileron and Rudder
- Rotary Hydraulic Drive Unit (HDU): LEF

Current F/A-18 Flight Line Leakage Limits

- Static Seals (All Servos): 1 drop/hr unpressurized, 2 drops/hr pressurized
- Horizontal Stab Servocylinder Dynamic Seals: 1 drop per 13 cycles
- TEF Servocylinder Dynamic Seals: 1 drop per 25 cycles
- Aileron and Rudder Dynamic Seals: 1 drop per 10 cycles
- LEF HDU Hyd Motor Shaft Seals: 100 drops/hr during motor normal ops

F/A-18 Flight Control Servo Leakage

Major Leakage Problems (All FC Servos)

- Heat-related compression setting of static and dynamic seals, regardless of geometry or application, identified as most common failure mode for servocylinders
  - F/A-18 does not contain permanent temperature monitoring system
    - Temp Tape monitoring recently implemented
  - Inherent difficulties isolating causes of elevated system temperatures can result in prolonged aircraft operation with hyd system temps well above nominal
  - Mil-P-25732 packings frequently discovered hard and brittle upon inspection
  - Mil-P-83461 packings used in limited applications, heat damage still experienced
- Piston Rod/Piston/Cylinder ID Dynamic Seal Wear
  - TEF Servocylinder Piston Seals
  - Horizontal Stabilator Piston Rod Seals (Center Dam)

Effect of Hot Hydraulic System on Leakage

Effect on MIL-P-25732 (MS28775) Nitrile Seals

- Compression setting, hardening, cracking
  - Permanent "squeeze" of packing
  - Elasticity/pliability lost
  - Identified by flat-sided oval cross-section
- Effect more acute for dynamic seals

Resulting leakage accounts for roughly <u>half</u> of all flight control servo removals

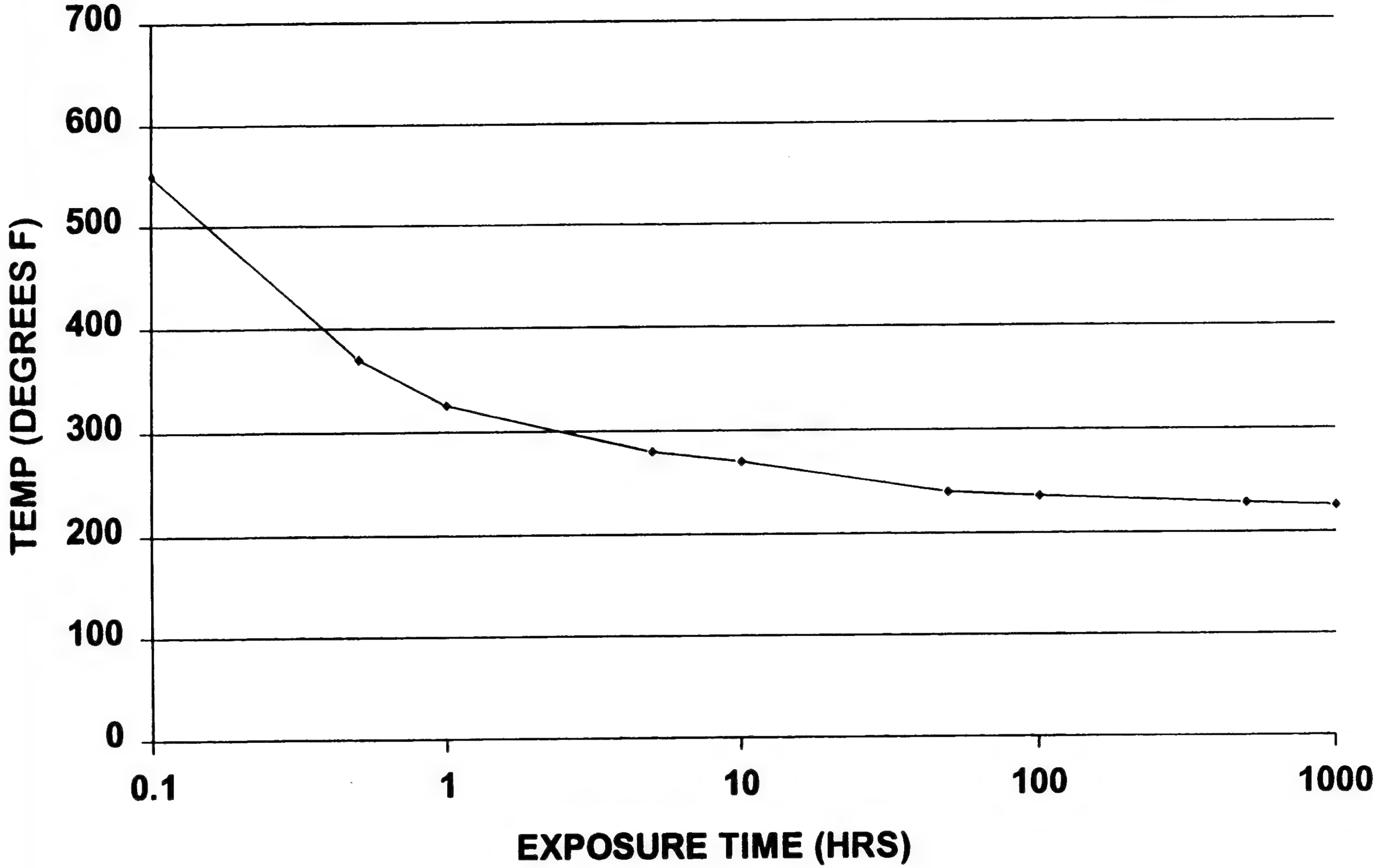
- Will affect every component in the system (not just the circuit)

System will function at elevated temps however, nitrile seal life <u>decreases</u> exponentially with increasing temp

PEO(T), F/A-18 IPT

MIL-P-25732 Seal Life vs Temp

TEAM HORNET



Man-hours Expended for Leakage

Total Fleet Maintenance Time Expended to Replace Leaking FC Components (July 94 - June 97)

TEF Servocylinder = 828 mh

LEF HDU Assembly = 1,026 mh

Aileron Servocylinder = 1,148 mh

Rudder Servocylinder = 3,353 mh

Horizontal Stabilator = 5,280 mh

Total = 11,635 mh (excluding repair and material costs)

F/A-18 Flight Control Leakage Data

Non-Cannibalization Removal Rates for Leakage: July 94 To June 97

- Trailing Edge Flap Servocylinder
  - 718 Total Removals
  - 138 Leakage (19%)
- Rudder Servocylinder
  - 1,217 Total Removals
  - 479 Leakage (39%)
- Aileron Servocylinder
  - 383 Total Removals
  - 164 Leakage (43%)
- LEF HDU/Servovalve Assy
  - 258 Total Removals
  - 114 Leakage (44%)
- Horizontal Stab Servocylinder
  - 1128 Total Removals
  - 528 Leakage (47%)

Horizontal Stabilator Servocylinder

Historically High Removal Rate for Leakage: 70% +

- Past reliability improvement efforts focused on primary cause for aircraft removal: Center Dam Dynamic Seal Leakage

Early Dynamic Seal Configuration

- Cylinder Center Dam, End Glands, Ram LVDT Transducer,
- Dual (vented) nitrile O-ring energizer with ID capstrip
- Nitrile susceptible to compression setting/loss of pliability (heat)

Efforts to improve overall MTBF and reduce leakage related removals resulted in implementation of new dynamic seal design

- TF spring-energized seals (TF888S222-902C)
  - Seals for latest servo configuration, P/N 3014000-6
  - Also installed at I and D level during servocylinder repair and 3014000 -5 to -6 upgrade

Maintenance data examined to determine if new dynamic seals effected improvement to leakage removal rates

PEO(T), F/A-18 IPT

Horizontal Stabilator Servocylinder

5-Year Study On Leakage Removals of Horiz Stab Servocylinders:

- July 92 - June 93: 70% (637 of 911 Total Removals)
- July 93 - June 94: 57% (449 of 781 Total Removals)
- July 94 - June 95: 56% (549 of 976 Total Removals)
- July 95 - June 96: 47% (507 of 1076 Total Removals)
- July 96 - June 97: 47% (532 of 1132 Total Removals)

Horizontal Stabilator Servocylinder

Study Findings

- Rate of removal for external leakage decreased from 70% to 47%
  - 23% drop in leakage removals in last 5 years due to implementation of spring-energized dynamic seals
  - Leakage removal rates have improved, but still remain high (47%)
- Fleet survey indicates that both manifold static nitrile seal and cylinder dynamic seal leakage is still occurring
  - Some leakage problems still experienced with TF dynamic seals
  - Compression setting of static seals common
- Additional analysis to be performed by NADEP North Island

Conclusions from Study

- Nitrile elastomer does not provide sufficient resistance/longevity when exposed to elevated hydraulic fluid temps
- Alternate seal material for static applications needed to substantially improve servocylinder reliability
- New dynamic seal designs needed for further reliability improvement

F/A-18 Hydraulic Seal Improvement Plan

Problem

- Mean Time Between Demand is low due to removal from A/C for external leakage
- The Mil-P-25732 nitrile seals currently used degrade when exposed to elevated hydraulic fluid temperatures
- Navy maintenance philosophy is to Inspect and Repair As Necessary

Solution

- NAVAIR/Boeing Program was established for testing and implementing high temperature Fluorocarbon GLT seal material (Viton)
  - Extreme temp test plan was developed to uncover any unforeseen failures - not an endurance test
- OEM's performed extreme temperature testing to verify heat resistance and cold weather leakage performance
  - -40 F to 300 F
  - More extreme than normal fleet ops (paint discoloration)

F/A-18 Hydraulic Seal Improvement Plan

Initial failures prompted additional testing

- TEF tested with current config nitrile seals in one system and fluorocarbon (Viton GLT) seals in other system
- 5 layers of cycling at 200 deg F added to original testing to see if face seal extrusion would occur at lower temps

Second round of testing results

- Fluorocarbon seals used as capstrip energizers leaked the same as the nitrile seals on piston rod
- Fluorocarbon face seals extruded again
  - Nitrile seals did not extrude
- Main Ram LVDT secondary Viton dynamic seals were torn in 2 of 3 servoyclinders (not found in 1st round of testing)
  - The seal is a capstrip with a fluorocarbon O-ring energizer
  - This failure occurred with the additional 10 hours of cycling at 200 deg F

F/A-18 Hydraulic Seal Improvement Plan

Extreme temp test plan was developed to uncover any unforeseen failures - not an endurance test

- 72 hour soak at 300 deg F
- 5 layers of:
  - 1 hour soak at -20 deg F
  - 2 hours cycling at 300 deg F
- Cold soak at -40 deg F, 3000 psi for 20 minutes and record leakage
- Commence cycling at -40 and perform ext leakage test
- Perform ATP

F/A-18 Hydraulic Seal Improvement Plan

Testing and inspection findings:

- No leakage from Rudder servocylinder or LEF SV's (no dynamic seals)
- Minor leakage at -40 deg F in Aileron servocylinder
- Minor leakage from 1 of 3 stabilator servocylinders
- TEF servocylinder dynamic and static seal leakage from all 3 test units
  - Unknown if caused by extreme temps or incompatible elastomer
- EHV face seal extrusion with no leakage
  - Suspected gland overfill phenomena

F/A-18 Hydraulic Seal Improvement Plan

Conclusions

- Static leaks occurred at -40, but disappeared after warming to -20 F
- Dynamic leaks on TEF and Stab piston rods were typical
- Evidence of dynamic seal tearing discovered on TEF

Implementation of fluorocarbon seals in F/A-18 FC servos will be limited to static seal applications only

- Fluorocarbon seals will not be used in EHV face seal applications

Dynamic Seal Design changes will be pursued for each actuator (AIL, RUD, TEF, STAB(?))

- May result in elastomer change, geometry change, or both

Biodegradable, Direct Replacement Hydraulic Fluids for Mil-H-5606 and Mil-H-83282

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Columbus, Ohio 43085
(614) 842-6600

METSS

Background

- Hydraulic Fluid Waste is Second Largest Waste Disposal Problem (Paint facility waste #1)
- Air Force Aims at 0% Waste Stream by 2000
- Program Driven by Environmental Awareness and Inevitable Mandates by the EPA
- European Community Leading the Development of New Biodegradable Fluids Including Replacement for MIL-H-5606 (Considering Outlawing All Mineral Oil Based Systems)

METSS

Objectives

- Define the environmental impact and performance expectations for MIL-H-83282 and 5606 hydraulic fluids used in applications where inadvertent leakage to the environment may occur.
- Develop a new product that degrades rapidly when inadvertently leaked or spilled in the environment and is nontoxic to aquatic life while providing satisfactory field performance.
- Evaluate currently available biodegradable hydraulic fluids to determine their performance according to military specifications
    - if results indicate meeting specs: recommendations for further qualification will be provided
    - if specs not met: suppliers queried for further development

METSS

METSS Phase I Actions

- Find suppliers and other hydraulic fluid experts to supply and/or prepare direct replacement fluids
- Set a protocol for specification testing through to determine the key physical properties of the biodegradable replacement fluid candidates.
- Provide the suppliers with a better understanding of the intent and significance of the program
- Establish baseline biodegradability factors for current AF hydraulic fluids
- Use the testing information to assist suppliers in optimizing hydraulic fluids with respect to various parameters
- Provide guidance to the AF in selecting the "best" fluids from the multitude of available hydraulic fluids for Phase II certification

METSS

Technical Approach

- A literature and market survey was conducted to review technology and to determine the availability of potential biodegradable hydraulic fluid replacements.
- Samples were collected for evaluation and a test plan was developed for materials qualification.
- Test results were reported to the material suppliers to allow reformulation.
- Key requirements were identified as:
    - -40C to 135C operating temperature range
    - compatibility with existing system components
    - low and high temperature stability

METSS

Program Kickoff Meeting

- Educated Hydraulic Fluid Suppliers on Goals of Program
- Encouraged Discussion to Further the Cause of the Program
- Solicit Industry Participation in Program

METSS

Initial Screening

- **Tests**
- Kinematic Viscosity at
  - -40F
  - 104F
  - 210F
- Low Temperature Stability Testing at -40F
- **Results**
  - 37 Samples screened
  - Only one sample failed high temp viscosity requirements.
  - 6 samples with high viscosity at -40F (reformulated samples provided)
  - 12 samples froze (eliminated from program)
- ***Suppliers were able to re-formulate products that failed initial screening tests or submit new products***

METSS

Further Testing

- Selected as Potential Problem Areas:
  - Accelerated Storage Testing (Army test method)
  - Hydrolytic Stability Testing (ASTM D2619)
  - L Rubber Swell Testing (FTMS 791, Method 5322)
  - Corrosion-Oxidation Testing (FTMS 791, Method 5308.7)
  - Four Ball Wear Testing (ASTM D4172)
- Six most promising candidates selected for additional testing

METSS

Environmental Aspects of Fluids

- A complex and ever changing web of statutes, regulations, guidelines, factual conclusions, and case specific interpretations form the legal framework.
- A complex set of chemical and physical properties determine the environmental properties.
- A complex system of chemical/biological interactions controlling toxicity.

- ***All these factors are inter-related and must be considered simultaneously!***

METSS

Biodegradation

1. **Primary (functional)** - biodegradation to the minimum extent necessary to change the identity of the compound
2. **Environmentally acceptable** - degradation to such an extent necessary to remove some undesirable property of the compound (e.g., toxicity, foaming).
3. **Ultimate** - the conversion of a compound to carbon dioxide, water, and additional inorganic compounds (mineralization)

METSS

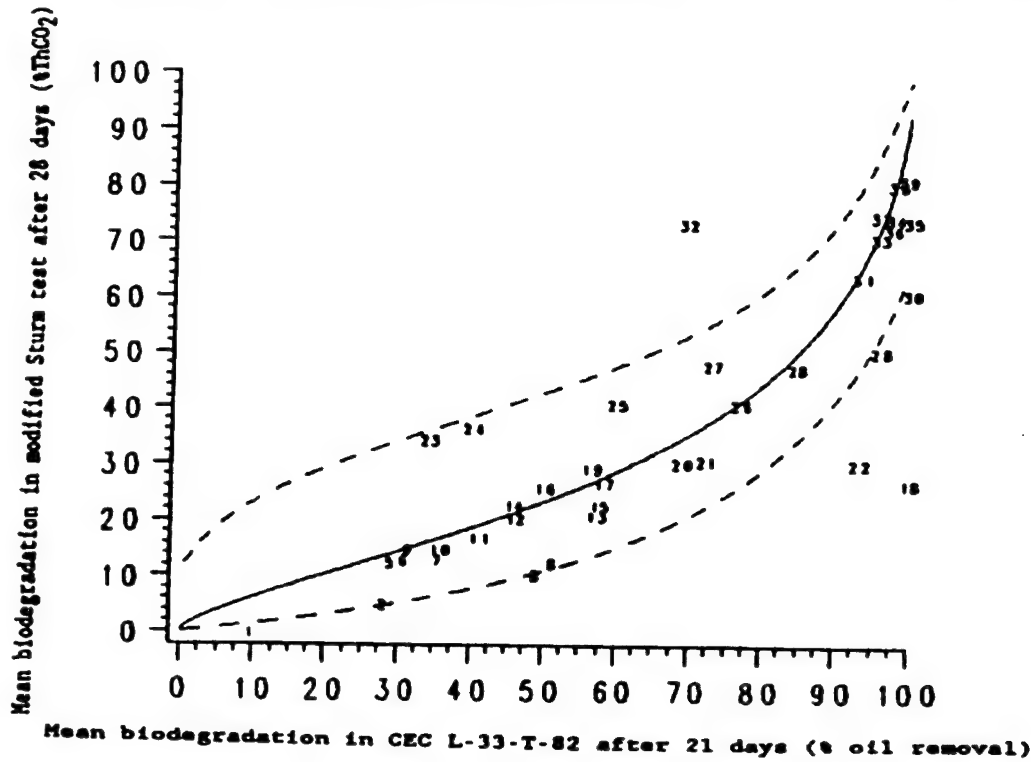
Test Method Coordinating European Council (CEC) L-33-T-82

- **Biodegradability of Two-Stroke Cycle Outboard Oils in Water**
- a de facto standard by which lubricants are generally are evaluated for biodegradability
- issued in 1982 to clean up pollution in lakes
- only a measure of primary degradation - utilized by most participants to quantify and qualify
- studies with lubricants have shown a direct correlation between the results of the CEC test and actual persistence in the environment.
- MIL-H-5606 and 83282 evaluated using this test method to establish baseline of biodegradability for Phase I
- petroleum oils characteristically biodegrade to around 30%

METSS

Correlation of CEC with Ultimate Biodegradability Test

Figure 2. Calibration curve of predictive model (———) with 95% confidence limits (- - - -). Numbers refer to Table 1.



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Classes of Hydraulic Fluid

Properties	Mineral Oils	Vegetable Oils	Synthetic Esters	Low Viscosity PAO
Biodegradability CEC- L33-T82	10-40%	70-100%	10-100%	75-90%
Viscosity Index	90 to 100	100 to 250	120 to 220	130 to 140
Pour Point, °C	-54 to -15	-20 to 10	-60 to -20	-60 to -40
Compatibility with Mineral Oils	-	Good	Good	Good
Oxidation Stability	Good	Poor to Good	Poor to Good	Good
Relative Cost*	1*	2 to 3	5 to 20	1.5 to 3

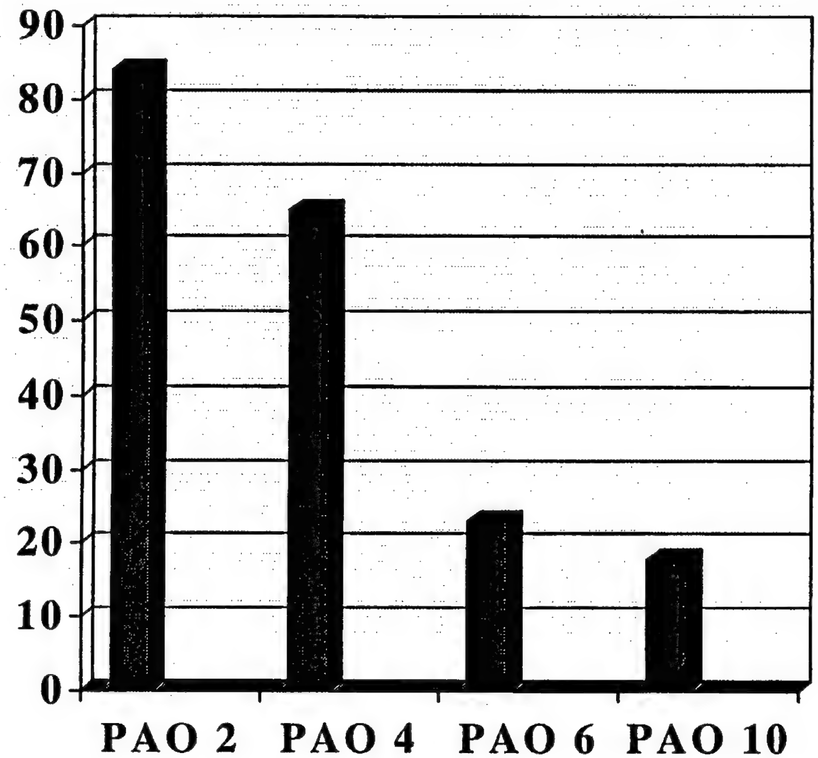
METSS

MILH - 87257

- MILH-87257 is a Synthetic Hydrocarbon (PAO) Based Hydraulic Fluid
  - Same chemistry as MIL-H-83282, but thinner (lower molecular weight)
  - AF developed
  - Conversion with no problems

METSS

PAO %Biodegradability vs. Viscosity



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CEC Biodegradability Test Results

Test Materials	Biodegradability (CEC-L-33-A-94)
MIL-H-83282	52%
MIL-H-5606	16%
DAB2	85%
P	95%
T	100%
AA	80%
U	98%
FF	85%
MIL-H-87257	84%

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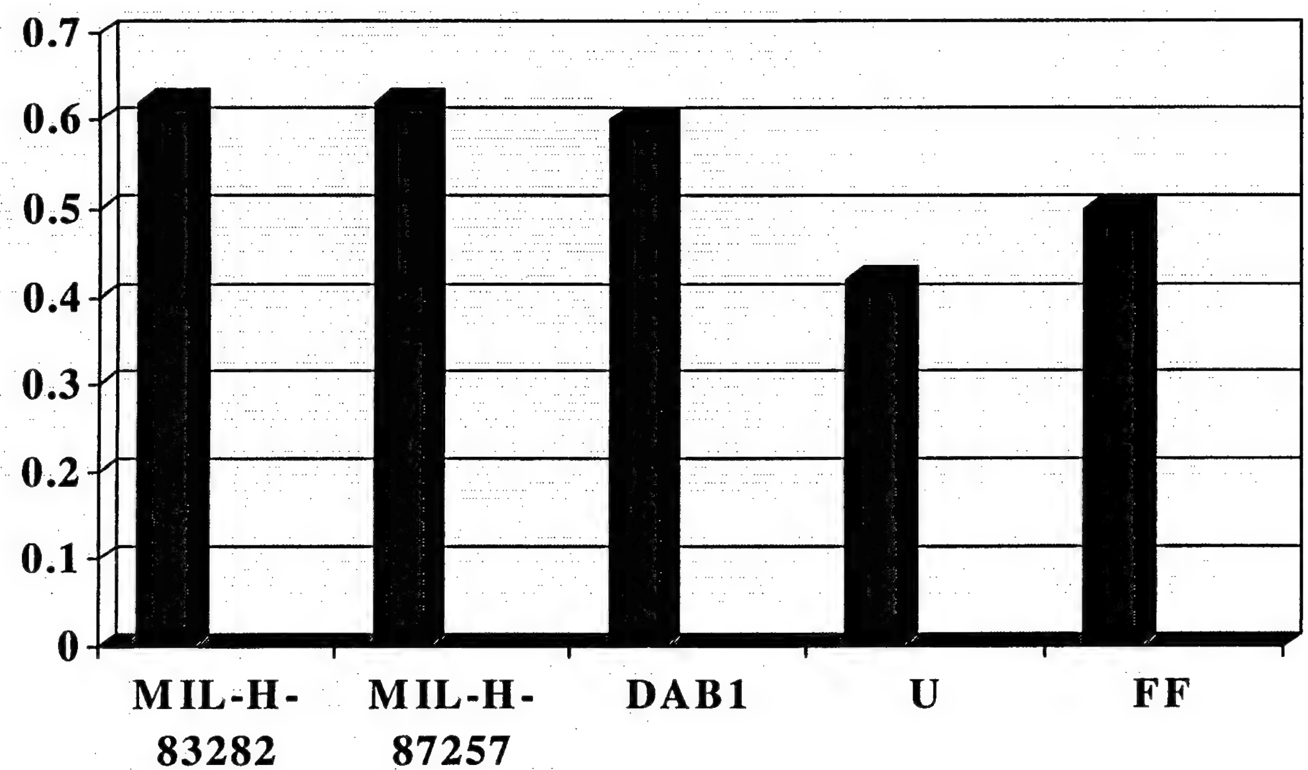
Four Ball Wear Scar, mm.



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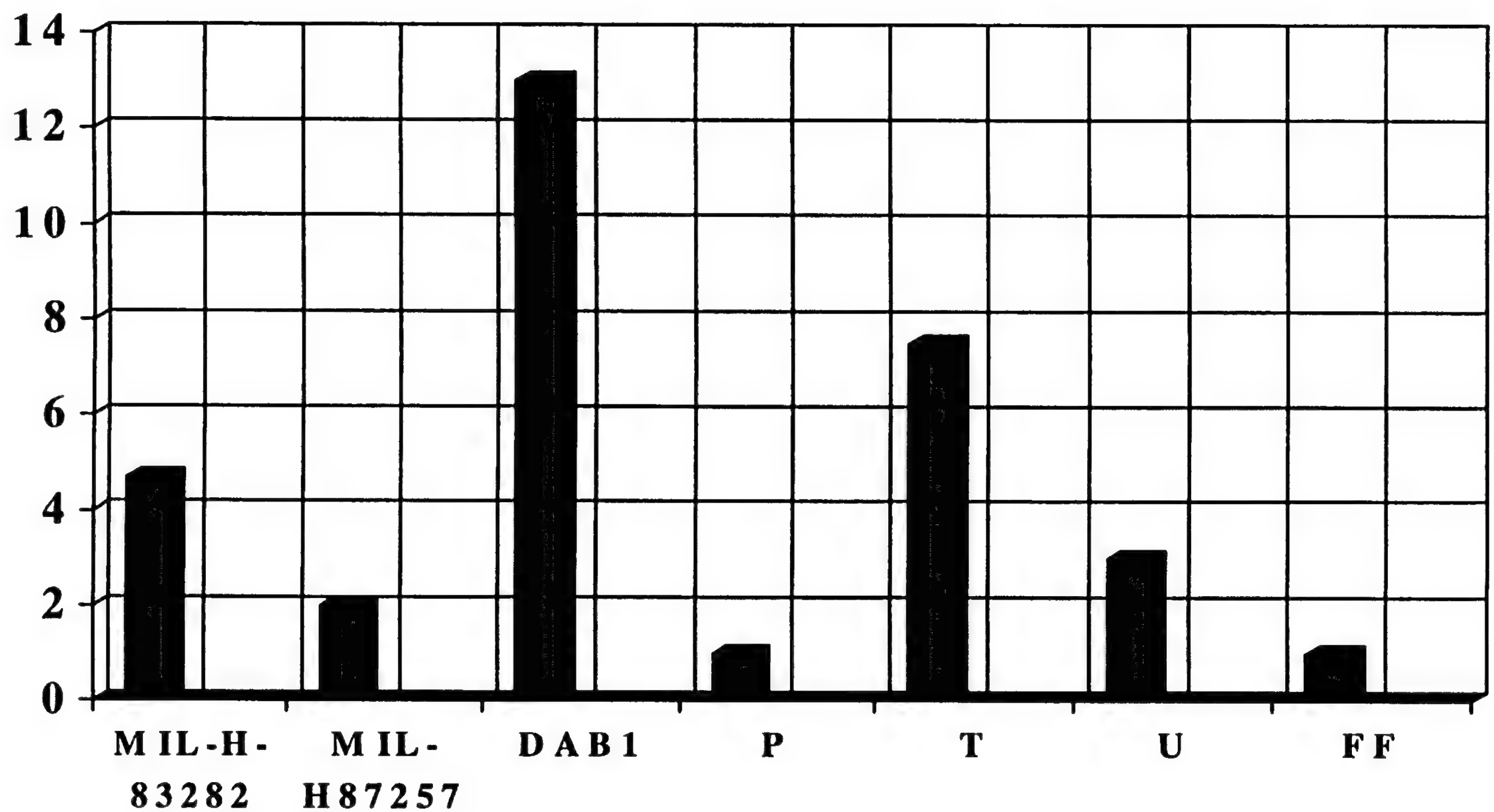
Accelerated Storage



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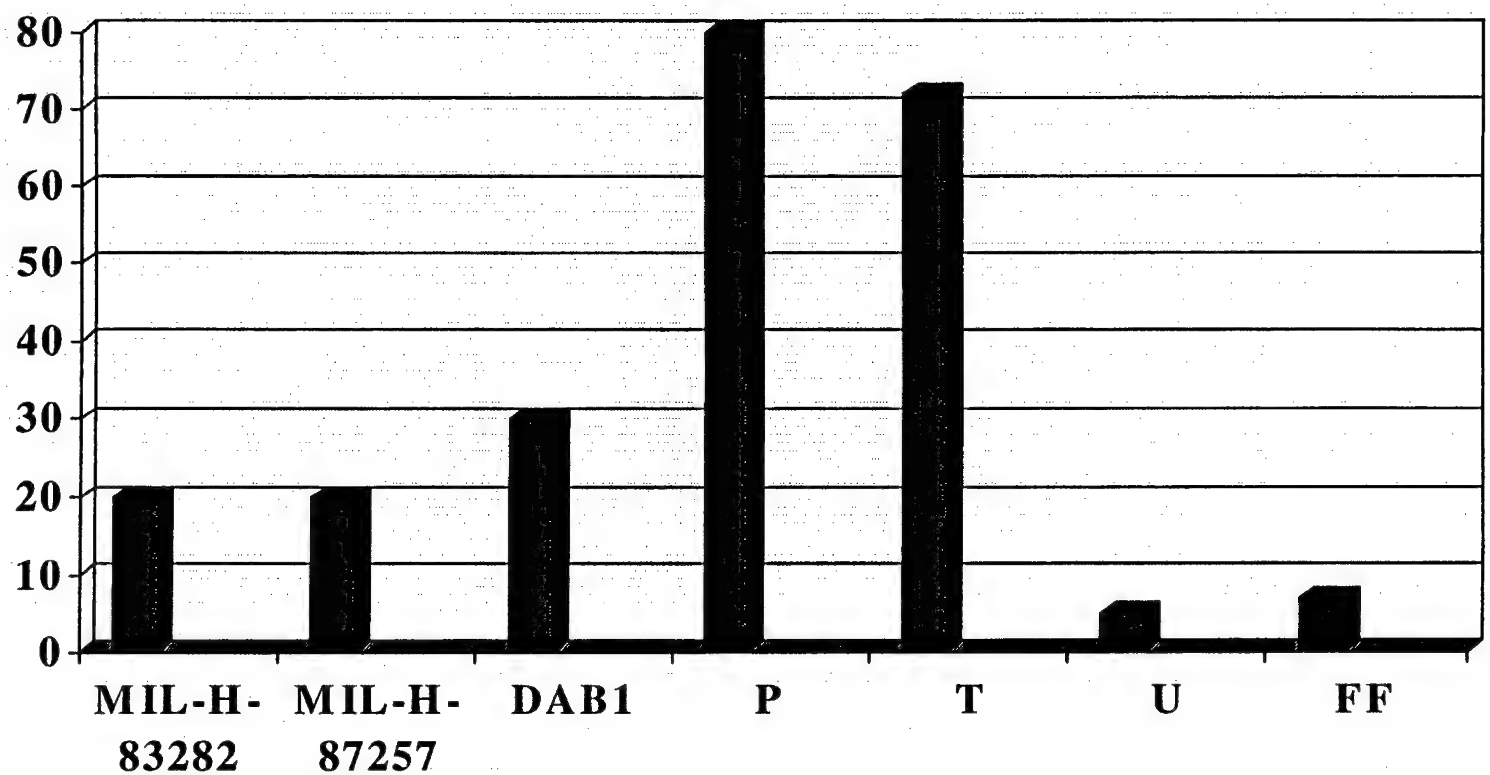
L-Rubber Swell Results



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Corrosion-Oxidation Stability

Fluid	Results
MILH-83282	Pass
MILH-5606	Pass
MILH-87257	Pass
DAB1	Fail*
U	Fail*
FF	Fail*

* Reformulated would probably pass

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Hydrolytic Stability Test Data

Fluid	Results
DAB1	Pass
U	Fail
FF	Marginal

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Results & Conclusions

- METSS has developed and assisted suppliers to develop a potential group of biodegradable environmentally compliant replacements
- The laboratory evaluation of fluids formulated from vegetable oils, synthetic esters and lower viscosity polyalphaolefins included viscosity, low temperature capability, elastomer compatibility, hydrolytic stability and biodegradability
- Testing has shown the MIL-H-5606 to be "nondegradable"
- MIL-H- 83282 exhibits "inherent (potential) biodegradability"
- MIL-H-87257 appears to be "readily biodegradable"
- The proposed replacement materials will be cost effective, drawing on existing materials and technology
- Several materials qualified in this initial screening
- These fluids provide the possibility of developing completely new environmentally compliant materials

METSS

Phase I Recommendations

- Further Evaluation of MIL-H-87257
- Investigation of Long-term Biodegradation of MIL-H-83282 (Could be Environmentally Acceptable)
- Further Evaluation of Five New Industry Formulations
- Further Evaluation of METSS New Formulation

METSS

Major Phase II Tasks

- ASTM Biodegradability Testing (short and long-term)
- Formulation Optimization
- Toxicological Assessment (Initial and Final)
- Economic Analysis
- Product Commercialization Plan
  - **Three Year Program**
  - **Additional Validation at WL/MLBT**
    - **Hydraulic Pump Testing and Dynamic Seal Testing**

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ASTM Standard D 5864-95

- **"Standard Test Method for Determining Aerobic Aquatic Biodegradation of Lubricants or Their Components".**
- will eventually serve as a basis for assessing the biodegradation characteristics of the candidate hydraulic fluids.
- covers the determination of the degree of aquatic biodegradation of fully formulated lubricants or their components on exposure to an inoculum under laboratory conditions
- specifically addresses the difficulties associated with testing water insoluble materials and complex mixtures such as found in many lubricants
- is designed to be applicable to all lubricants that are not volatile and are not inhibitory at test concentration to the organisms present in the inoculum

METSS

Steps for the Phase II Program

- ***ASTM Biodegradability Testing***
  - Mil-H-83282 and Mil-H-5606 will determine the baseline reference data
  - Mil-H-87257 hydraulic fluids
- **Other Biodegradability Issues - The AF definition of biodegradability**
- **Toxicological Screening**
- **New Hydraulic Fluid Development**

METSS

Phase II Direction

dictated by the ultimate biodegradability testing of Mil H87257

- **positive** - emphasis will be placed on qualifying materials
  - If the Mil-H-87257 materials can be qualified as biodegradable over a reasonable time frame, the Air Force will recognize a significant cost saving as the expense of re-qualifying a new material will be avoided.
  - **mixed** - possible causes and suggestions for reformulation will be made as necessary.
  - Extreme care will be taken in this instance to avoid making any formulation changes that would mean the materials would have to be re-qualified
  - **negative** - formulations will be reviewed
  - Reformulating these materials for biodegradability may be easier than reformulating and qualifying the other (non mil-spec) materials.
- ***This route may ensures a higher probability of program success***

METSS

Biodegradability: AF Definition

- Characterize the time frame for 100% biodegradation of Mil-H-87257 and Mil-H-83282 to provide a benchmark.
- Set a clearer definition of biodegradability as defined by the ASTM test in real world scenarios
    - Class I - 60% degradation after 28 days of testing.
    - Class II - 60% in 84 days
    - Class III - 40% in 84 days
    - Class IV - none of above
- ***Mil-H-83282 may also exhibit complete biodegradability in a time frame the Air Force considers acceptable for certain operations which will provide the Air Force with an option to specify a flame resistant biodegradable hydraulic fluid.***

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Phase II: Anticipated Benefits

- Provide the Air Force with a commercially available environmentally attractive alternative to hydraulic fluids which represent maximum biodegradability and minimum deviation from the military performance needs.

- Reduce the problems with the "cost of ownership" of hydraulic fluids, that is, acquisition to disposal/recycle

- Eliminate the spill and leakage concerns with the hydraulic fluids used in Air Force and, thereby, reduce the amount of hazardous waste generated by the Air Force maintenance and repair operations.

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Hydraulic Fluids and Seals Workshop: *Barium-Free Corrosion Inhibitors*

Kenneth Heater, PhD
METSS Corporation
720-G Lakeview Plaza Blvd.
Columbus, Ohio 43085
(614) 842-6600

METSS Corporation

- Established in 1994
- Experience base in contract research/ product development
- 12 employees and growing (5 PhD's)
- 6500 ft^2 office and lab space (Columbus)
- Goal - Develop environmentally friendly products and processes through *applied* technology.

METSS

Current Projects

- Heavy metal free corrosion inhibitors*
- Biodegradable hydraulic fluids*
- Environmentally friendly DFLs
- Environmentally friendly/food grade dielectric fluids (cables & transformers)
- Environmentally benign deicing fluids (roadway/aircraft)
- Environmentally friendly recycling/cleaning processes
- Chemical sensors for quality, environmental and process monitoring

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Hydraulic Fluids - Problems

- Heavy metals used as corrosion inhibitors in hydraulic fluids and lubricants.
- Many hydraulic fluids and lubricants are toxic to humans and the environment.
- Most hydraulic fluids and lubricants are NOT biodegradable.

➲ *Goal - develop/integrate technologies to create 100% green hydraulic fluids/lubricants*

METSS

Challenge

- Develop environmentally friendly *direct replacement*, hydraulic fluids and lubricants.
- Direct replacement means materials that will:
  - meet the physical property requirements of existing fluids
  - meet in-service performance requirements
  - meet materials compatibility requirements.

➲ *We would like our materials to meet existing military or industry specifications*

METSS

Solution

- Develop environmentally friendly alternatives that address critical design elements, without the use of heavy metals or toxic chemicals, using materials that biodegrade into totally benign elements:
  - non-metallic salts and synergistic additives
  - avoid petroleum/mineral based fluids
  - controlled biodegradation into H_2O, CO_2, energy.

METSS

How do we do this?

- Well defined technical program:
  - ❶ identify needs, evaluate existing fluids
  - ❷ select candidate alternative materials
  - ❸ develop testing and evaluation program
    - lab-scale experiments
    - small-scale testing
    - in-service testing and evaluation
  - ❹ conduct iterative formulation, testing, and optimization program

❹

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Typical Program Results

- Commercially available materials identified that meet program needs
  - product commercialization route in place
- New formulations developed using a blend of commercially available materials
  - may work with major component supplier to commercialize technology
  - toll manufacturing/industry partnerships
- New chemistries/formulations developed
  - major component supplier/licensing

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Ba-Free Program - Background

- Rust-inhibited hydraulic fluids are used during maintenance/storage operations to protect aircraft hydraulic components from corrosion
- Corrosion can lead to failure by plugging or destroying critical surfaces around seals
- Current fluids do not exhibit the temperature stability needed to support in-flight use
- Fluids must be drained from parts and replaced with non-inhibited fluids prior to aircraft installation

METSS

Ba-Free Program - Problem

- Existing fluids contain barium, a heavy metal slated for elimination from DoD use
- Fluids containing barium are considered hazardous waste
- Waste generation and subsequent disposal costs are significant (hydraulic fluids are second largest AF waste stream)

METSS

Ba-Free Program - Objective

- Develop non-barium containing corrosion inhibited hydraulic fluids for Air Force and DoD use
  - environmentally compliant (no heavy metals)
  - equivalent or better corrosion inhibition performance than barium
  - meet existing military specifications
  - pass mission critical tests (e.g., pump tests)
  -

METSS

Current Fluids

- Applicable MIL-Spec
  - MIL-H-46170B - Hydraulic Fluid, Rust-Inhibited, Fire Resistant
- Current Fluids
  - MIL-H-83282 Basestock
  - Ba-DNNS - DNNS inhibitor (2-3 wt%)

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Candidate Materials

- Existing commercial products
  - drew on technologies currently being used in lubricants and coatings industry for corrosion control
- Formulations developed from existing commercial products
- Formulations developed from materials synthesized by METSS

METSS

Formulation Development

- Evaluated baseline performance of candidate materials in basestock oil
  - concentration effects
- Developed/tested candidate formulations
  - critical concentration ratios
- Optimized performance of best candidates
  - tiered approach to testing
    - simple screening tests to eliminate poor performers
    - more advanced tests to optimize formulations
    - final qualification tests to select best performers

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Performance Criteria

- CREP Test Performance
- Physical Property Requirements
- Toxicology
- Corrosiveness
- Oxidation Stability
- Thermal Stability
- Wear Testing
- Air Force Testing

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CREP Test

- Developed by Air Force and Pratt & Whitney
- Accelerated test for evaluating relative corrosion protection of inhibited oils
  - environment: 99°C, 100 RH, distilled water or 25% acetate buffer solution*
  - samples: 1010 steel, sanded, dipped in test oil
  - duration: 1-8 hr.
  - rating: CREP rating (1-10), weight change, barium control

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Physical Properties

Viscosity in cSt @ 40°C (max)		***19.5***
Viscosity in cSt @ 100°C (min)		***3.4***
Viscosity in cSt @ -40°C (max)		***2600***
Viscosity in cSt @ -54°C (max)		***Report***
Trace sediment, mL (max)		0.005
Evaporation loss, wt. % (max)		***5.0***
Flash point, °C (min)	Type I/Type II	218/204
Fire point, °C (min)		246
Pour point, °C (max)		-54
Water, wt. % (max)		0.05
Acid or base number, mg. KOH/gm (max)		***0.2***
Auto-ignition temperature, °C (min)		343
Bulk modulus (isothermal secant, 0 to 6.8×10^4 kPa) (0 to 10,000 psi) at 40°C, kPa (psi), (min)		1.379×10^6 200,000
Water sensitivity, % transmittance (min)		90%

METSS

OC Testing

- Oxidation-Corrosion Testing
  - 168 hr @ 135°C
  - viscosity change (<10%)
  - acid number change (<0.3)
  - evaporation loss (<5%)
  - weight change (±0.2 mg/cm^2 for Mg, Al,Cd, Steel, ±0.6 for Cu)
  - copper appearance (< No. 2 per ASTM D130)

METSS

Other Testing

- Toxicology Assessment - best available data
- Thermal Stability - 100 hr @ 205°C, 1 L/hr N_2
  - < 5% change in 40°C viscosity
  - < 0.1 increase in acid number
  - no precipitation/insoluble matter
- Wear Testing (ASTM D2266)
  - 0.3 mm scar @ 10 kg, 0.65 mm scar @ 40 kg
- Air Force Testing
  - valve sticking test
  - elastomer dynamic pump test
  - pump test
  -

METSS

Phase I Program

- CREP Testing*
- OC Testing
  - Viscosity and Viscosity Change
  - Acid Number and Acid Number Change
  - Metal Weight Change
  - Copper Appearance

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Phase I Results - Viscosity

		MLO Number			
Viscosity (cSt)	**Spec. Value**	95-249	95-250	95-251	95-252
-54 °C	**Report**	13872	13832	13300	13280
-40 °C	**2200 (max)**	2321	2366	2266	2311
40 °C	**19.5 (max)**	NR	NR	NR	NR
100 °C	**3.45 (min)**	3.69	3.76	3.73	3.66
200 °C	**Report**	1.17	1.17	1.15	1.15

NR = specific values not reported; 14 – 16 cSt is average range at 40 °C

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Phase I Results - OC Testing

		MLO Number			
		95-249	95-250	95-251	95-252
Fluid Property Changes					
% Vis. change at 40°C	**10 (max)**	0.66	2.60	0.93	1.29
Orig. acid number (mg KOH/g)	**0.2**	1.39	2.14	1.19	2.21
Acid number change	**0.3 (max)**	0.08	0.40	0.03	0.10
% fluid weight loss	**5%**	0.63	0.66	0.57	0.65
Metal weight change (mg/cm^2)					
Cd	**0.2 (max)**	0.01	0.03	0.02	*0.30*
Mg	**0.2 (max)**	0.01	0.03	0.01	0.03
Steel	**0.2 (max)**	0.00	0.02	0.00	0.03
Al	**0.2 (max)**	0.01	0.02	0.00	0.03
Cu	**0.6 (max)**	0.07	0.01	0.07	0.0
Copper Appearance: (ASTM D130)	**2 (max)**	1b	3a	1b	3a

METSS

Phase I Results - Other

- Formulations developed:
  - are environmentally friendly/benign
  - performance exceeds that of the Ba-DNNS corrosion inhibitors
  - can be used at lower concentrations than Ba-DNND (less expensive?)
  - demonstrate superior thermal/oxidative stability relative to the barium inhibited control (potential use in aircraft operation - eliminate change-out, decrease waste)
  -

METSS

Barium-Free Phase II Program

- Phase II Objectives:
  - fully optimize the performance of corrosion inhibitor formulations against a stringent testing and evaluation program
  - toxicological assessment
  - scale-up and qualify product formulations
  - determine and address cost of ownership issues
  - perform market assessment and develop product commercialization plan

METSS

Current Status of Phase II

- Number of alternative formulations developed
  - CREP performance up to 3X Ba-DNNS control
  - acid number requirements met
  - excellent OC results
  - thermal stability tests in progress
  - about to move on to scale-up efforts
  - investigating commercialization routes

METSS

Closing Comments

- Feasibility of developing high performance, heavy metal-free corrosion inhibitors well established
- About 1 year away from completion of project goals
- Project commercialization efforts need to be explored

METSS

MIL-H-53119 Nonflammable Hydraulic Fluid and Sealing Technology

17 March 1998

Lois Gschwender

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Outline

- Background
- Fluid R&D
- Seal R&D
- ML Pump Testing
- External Contract Hardware/System Development
- Summary

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

USAF Noncombat Hydraulic Fluid Fire History

Yrs	Hyd Fluid Used	$ Losses
70-79	MIL-H-5606	~20M/Yr
80-82	MIL-H-5606/83282	~ 6M/Yr
83-86	MIL-H-83282/5606	~ 1M/Yr
87	MIL-H-83282/5606	~$260M (B1/5606)
88-94	MIL-H-83282/5606	~ 1M/Yr

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Background

- **1975 Meeting in Pentagon - AF Use of MIL-H-83282**
  - **Decided not to convert to MIL-H-83282**
    - **Confused about *Fire Resistance***
      - **Some flammability properties no better than MIL-H-5606 - Not sure of improvement**
  - **Gen. Evans requested that team determine feasibility of developing nonflammable hydraulic fluid (without constraints)**

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

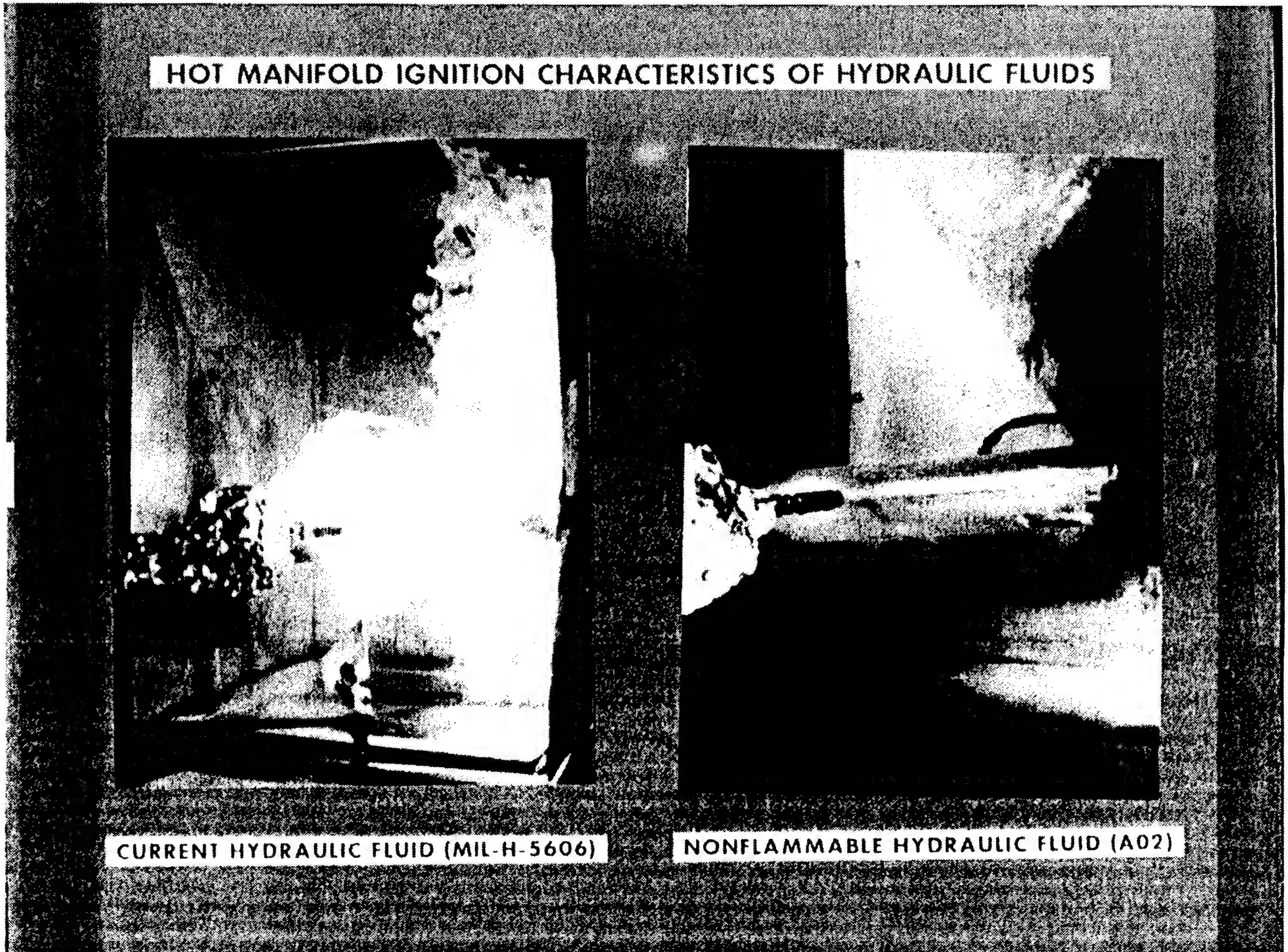
Established integrated, interdisciplinary team for the research and development program

- Air Force In-house Activities - Materials Laboratory, Propulsion Laboratory, Flight Dynamics Laboratory
- Fluids, Seals, Hydraulic Component and Aircraft Hydraulic System Contractors
- Private Industry (Unfunded)
- Tri-service coordination

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Flammability Characteristics had to be developed to define *Nonflammable* (Established by Hazards Branch)

Test	Criteria A (Rejected Take-Off)	Criteria B (Min. Acceptable)
Heat of Combustion	0	<5000 BTU/LB
Hot Manifold Ignition	$\geq 3000^{o}$ F	$\geq 1700^{o}$ F
Minimum Autogenous Ignition Temperature	$\geq 2600^{o}$ F	$\geq 1300^{o}$ F
Atomized Spray Flam-mabilty (A) Arc/Spark (B) Propane Air Flame (C) Incendiary Gunfire	Fluid May Ignite, But Must Self Extinguish	


HOT MANIFOLD IGNITION CHARACTERISTICS OF HYDRAULIC FLUIDS
CURRENT HYDRAULIC FLUID (MIL-H-5606)
NONFLAMMABLE HYDRAULIC FLUID (A02)

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

- **Hydraulic Fluid Properties Defined by Mechanical Systems Group**

Operating Temperature Range (^{o} F)	-65 to $\geq$ 275
Kinematic Viscosity (cSt)	$\leq$ 2500 @ -65^{o} F and $\geq$1.5 @ 275^{o} F
Pour Point (^{o} F)	$\leq$ -75
Weight (lb./gallon)	~ 14
Bulk Modulus (psi)	$\geq$ 120,000 @ 3000 psi in operating temperature range
Lubricity (mm wear scar)	$\leq$ 1.0 at 40 Kg load
Elastomer Compatibility	No shrinkage, 15% max. vol. swell
Metal Compatibility	Can readily use available metals
Fluid Stability	No change in chemical properties within operational temperature and pressure range
Foaming	$\leq$ MIL-H-5606

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Fluid Development

Extensive Number of Fluid Classes Investigated

- Phosphate Esters
- Synthetic Hydrocarbons
- Perfluorinated Alkylethers
- Phosphazines
- Triazines
- Chlorofluorocarbons
- Fluoroalkyl Ether
- Fluorinerts
- Silicones (Nadraul MS-5 and MS-6)

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Two final Candidates

$Cl(CF_2CFCl)_nCl$

Chlorofluorocarbon (CTFE)

- Halocarbon Products

$C_3F_70(\underset{\substack{|\\ CF_3}}{C}FCF_20)_n\underset{\substack{|\\ CF_3}}{C}F\text{-}CF_2H$

Fluoroalkylether (FAE)

- DuPont

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Property	Goal	CTFE	FAE	5606	83282	Phos. Ester
Flash Pt., °F	none	none	none	220	425	360
Fire Pt., °F	none	none	none	230	490	420
AIT, °F	≥ 1300	1,170	1,170	435	650	950
Ht of Comb, BTU/lb	≤ 5000	2,390	1,780	18,100	17,700	12,800
Atomized Spray	No Comb.	No Comb.	No Comb.	Sustains	Sustains	Extinguishes
Hot Manifold Ignit.						
Stream, °F	≥ 1700	>1700	>1700	730	630	1,440
Spray, °F	≥ 1700	>1700	>1700	1,330	1,250	1,500
Viscosity, cSt						
@ -65 °F	≤ 2,500	2,518	3,068	2,127	11,500	3,500
@ -40 °F	≤ 500	524	501	500	1,900	600
@ 275 °F	≥ 1.5	1.4	1.0	3.4	2.3	2.5
Vapor Press, Torr						
@ 300 °F	≤ 100	71	25	60	1.2	N/A
Bulk Modulus, psi						
@ 275 °F	≥ 120,000	110,000	75,000	120,000	145,000	180,000
Lubricity, mm Scar	≤ 1.0	0.87	0.61	0.85	0.48	0.68
Cost @ 1M G/Yr		$ 60	$200	$3.60	$8.10	$20.60

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Based on balance of compliance of properties and cost and availability, CTFE oligomer selected as primary candidate

Fluoroalkyl ether was more expensive and had lower bulk modulus. In addition, DuPont, the sole source, discontinued production of the fluid.

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

<u>Status of Component Development</u>

- No new hydraulic components developed for CTFE
  - Minor modifications only
    - Substitute compatible elastomers for BUNA-N if present
    - Increase pump inlet pressure
- Program provided for optimization of hydraulic components and systems for unique properties of nonflammable hydraulic fluid

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

<u>Program Goal Redirection</u>

- In late 1980's, only new aircraft in planning was Advanced Tactical Fighter - a predicted -65 F to 350 F, 8000 psi hydraulic system aircraft.
- Of the CTFE formulation at that time
  - Rust inhibitor (BSN) only stable to 275 F
  - Lubricity additive (3M) stable to 400 F
  - Base fluid film load carrying ability uncertain

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

CTFE - 350°F Version

- For 350°F, King Industries' zinc dinonylnaphthalene sulfonate with a zinc salt (ZnHT) was stable and found to be even better than BSN for antirust - less hygroscopic, better rust protection.
- Total formulation worked for 8000 psi, 20 gpm pumps, but not 8000 psi, 40 gpm pumps.

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Seals R & D

- For -65 to 275 F, 3000 psi
  - Phosphonitrilic fluoroelastomer (PNF) (Gum no longer commercially available.)
  - Ethylene - propylene diene monomer (EPDM)
- For -65 to 350 F, 8000 psi
  - Fluorocarbon elastomer, Viton GLT (good low temperature)
- Special seal design is critical to high pressure sealing and has been validated.

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Specification - MIL-H-53119

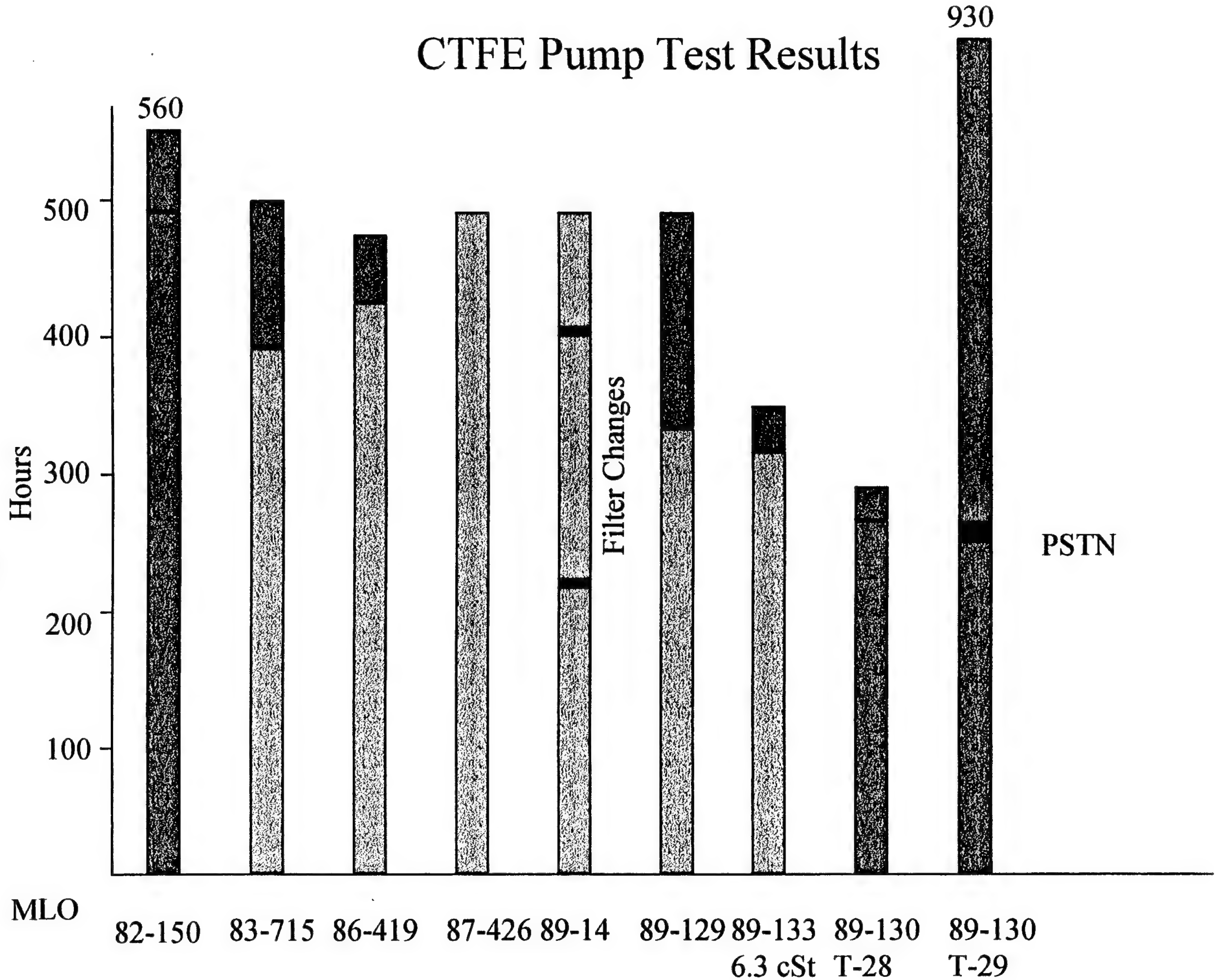
- Wright Lab wrote around prototype material
- US Army, Ft Belvoir, issued as an Army specification because a document was needed for their test programs in tanks, howitzers and ground equipment.

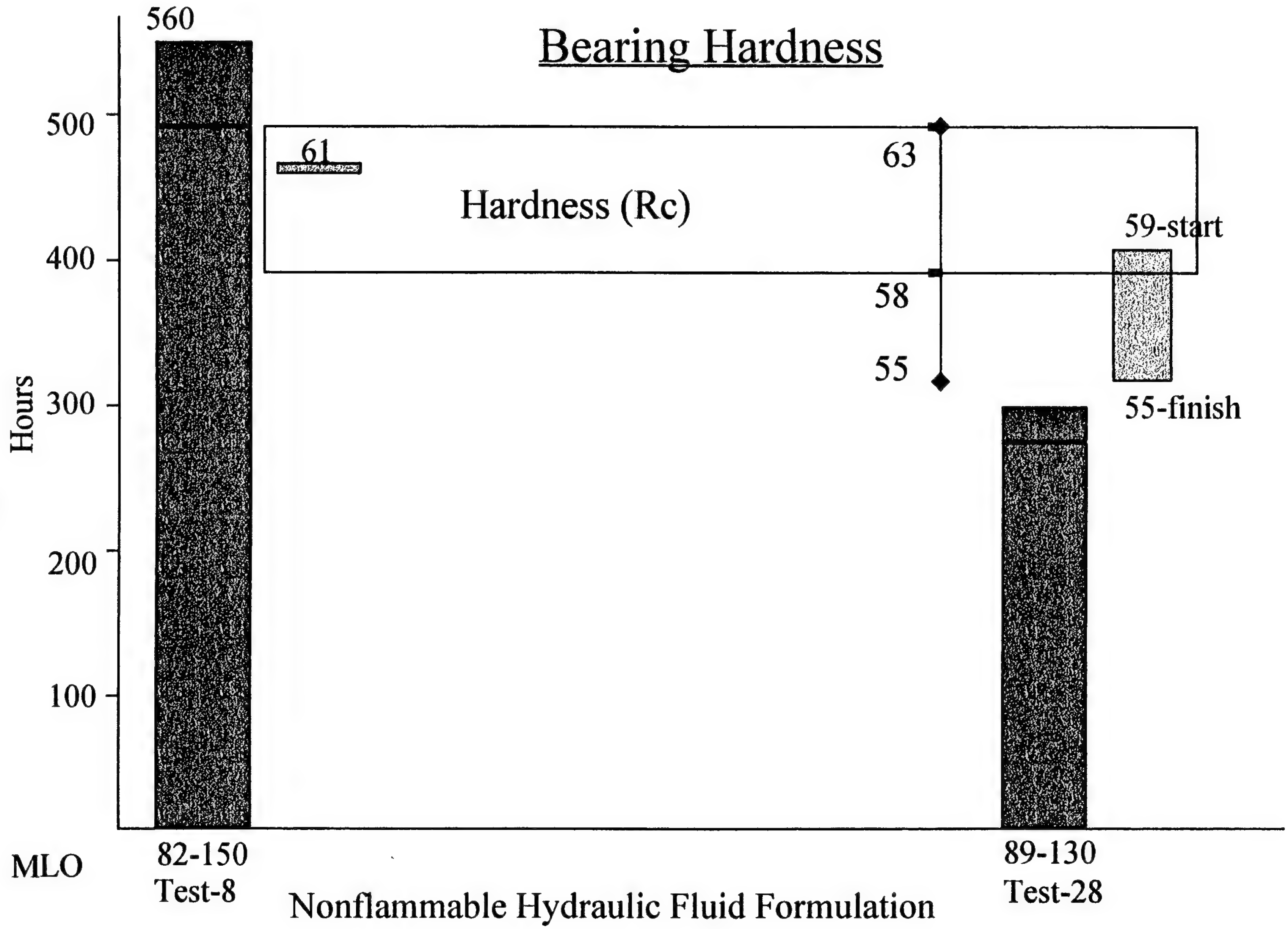
MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

<u>ML Pump Tests</u>

- Extensive tests of various formulations with F-16 EPU, Vickers PV3-075 state-of-the-art axial piston pump
- Only modification was use of Viton GLT seals to replace Buna-N
- Successfully validated formulations, 275°F and later 350°F versions

CTFE Pump Test Results





Bearing Hardness
560
500
400
300
200
100
Hours
61
Hardness (Rc)
63
58
55
59-start
55-finish
MLO
82-150
Test-8
Nonflammable Hydraulic Fluid Formulation
89-130
Test-28

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

MLBT Pump Test Findings

- MIL-H-53119 was successfully pump tested
- Higher hardness thrust bearing steel increased pump life
- M-50 thrust bearing performed far superior to 52100 thrust bearing

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

<u>External Contracts - System Hardware</u>

- Boeing KC-135 Fireproof Brake System
- Lockheed High Technology Test Bed
  - Simulator tests - 866 hours (8000psi)
  - Flight test - 250 hours (8000psi)
- McDonnell-Douglas Aircraft Flight Simulator - Extensive validation of all aspects of CTFE hydraulic system (8000psi)

MIL-H-53119 Nonflammable Hydraulic Fluid/Seals

Summary

- Based on a requirement for a totally nonflammable hydraulic system, MIL-H-53119 fluid, compatible seals and associated hardware were developed and demonstrated.
- Nonflammable hydraulic system technology is available for the right application.

Moisture Levels Causing Ice in Hydraulic Fluid

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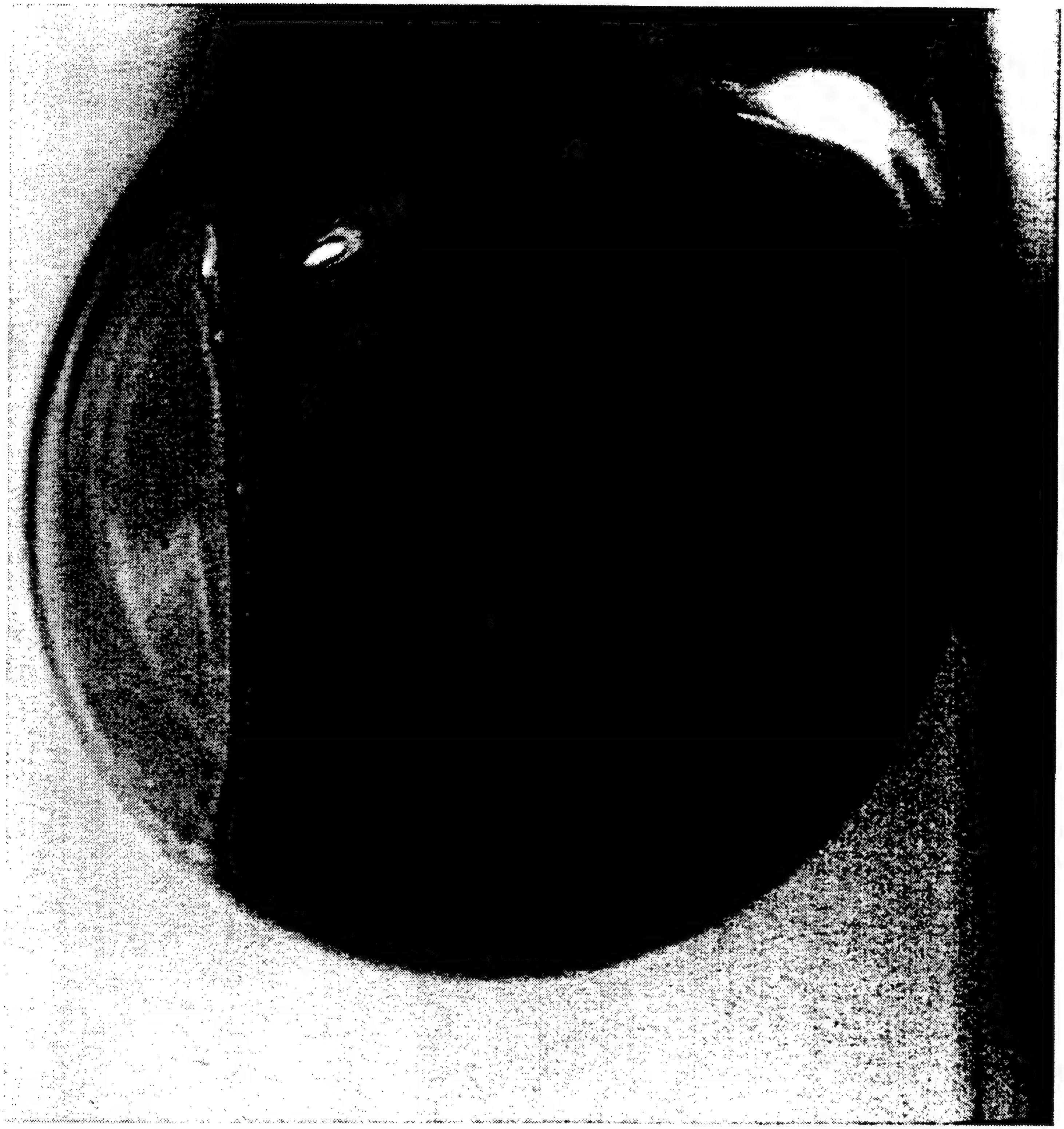
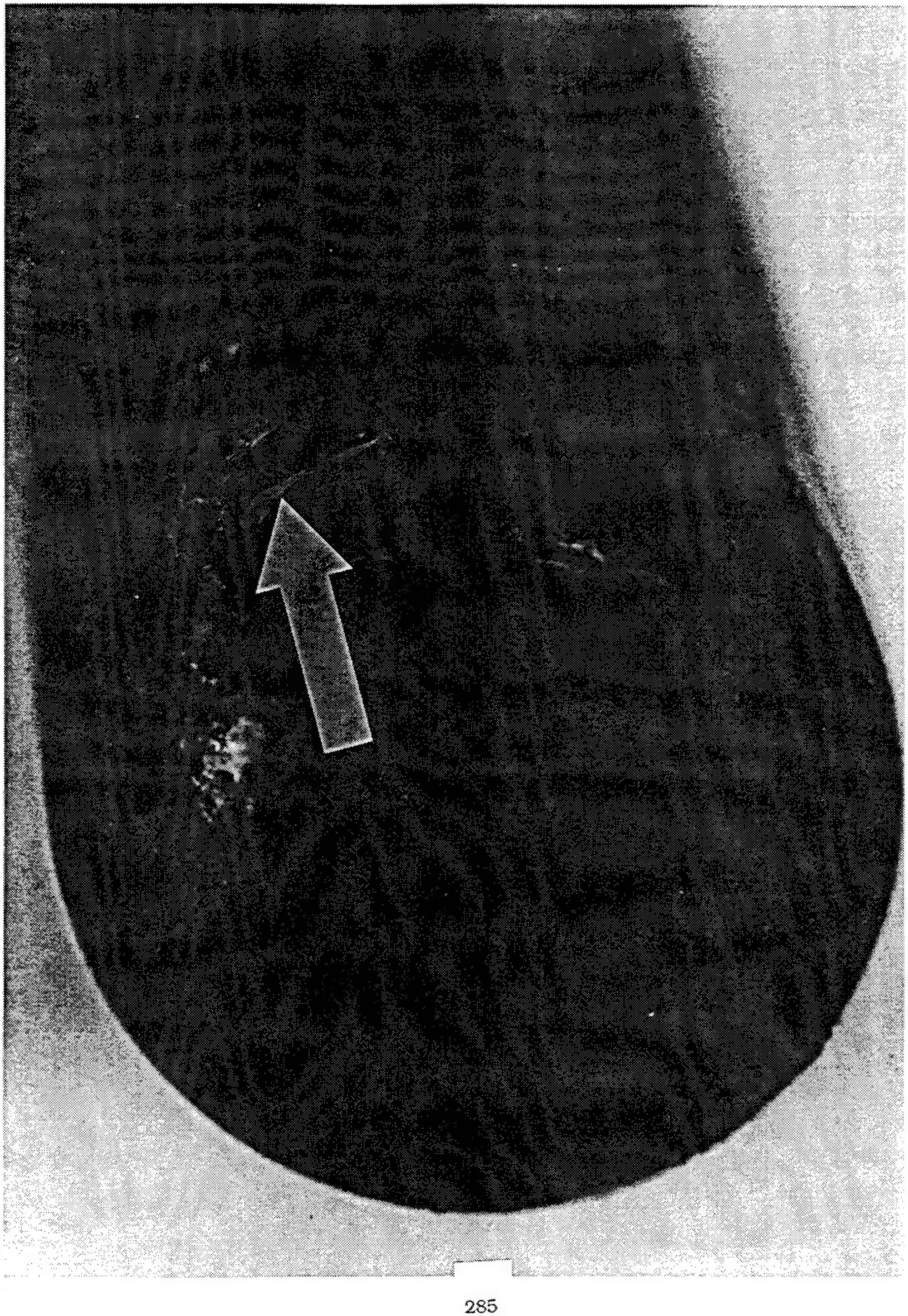




AC9809/usda - 3

MIL-H-83282 Freezing and Warm-up Cycle Test

10-13 March 1997

Theoretical Water (ppm)	Initial Appearance	2nd Day		3rd Day		4th Day		K-F Determination of water (ppm)	
		-40°C	Room Temp	-40°C	Room Temp	-40°C	Room Temp	Run 1	Run 2
222 ppm	Clear	Light haze	Clear	Med. Haze	Clear	Cloudy	Clear	182	189
298 ppm	Clear	Light haze	Clear, fine drops	Med. Haze	Clear	Cloudy	Clear	313	310
386 ppm	Clear	Light haze	Clear, small drops	Med. Haze	Clear, oil on outside of tube	Cloudy	Clear	323	321
586 ppm	Clear	Light haze, ice	Clear, small drops	Med. Haze	Clear	Cloudy	Clear	453	445
760 ppm	Clear	Cloudy, ice	Clear, small drops	Cloudy	Heavy haze	Cloudy	Light Haze	643	636
930 ppm	Cloudy	Cloudy, ice	Cloudy, small drops	Cloudy	Heavy haze	Cloudy	Med. Haze	729	725
1131 ppm	Cloudy	Cloudy, ice	Heavy Haze, small drops	Cloudy	Cloudy	Cloudy	Cloudy	1066	1054
1271 ppm	Cloudy	Cloudy, ice	Cloudy, small drops	Cloudy	Cloudy	Cloudy	Cloudy	1206	1204

Samples were placed in a ultrasonic bath for approximately 1 hour and then hand shaken before placing them in the cold bath.
The test samples appeared to have some fine dust particles or air in the samples.
MLSS 97-17 (MIL-H-83282) hydraulic fluid contained 38 ppm of water.

MIL-H-83282 Freezing and Warm-up Cycle Test

24-27 Feb 1997

Theoretical Water (ppm)	Initial Appearance	2nd Day		3rd Day		4th Day		K-F Determination of water (ppm)	
		-40°C	Room Temp	-40°C	Room Temp	-40°C	Room Temp	Run 1	Run 2
250 ppm	a	cloudy, ice 1	clear, trace	cloudy	clear	cloudy	clear	232	227
270 ppm	a	cloudy, ice 1	clear, a drop	cloudy	clear, a drop	cloudy	clear	273	275
398 ppm	a	cloudy, ice 2	clear, many small drops	cloudy, ice 2	clear, many small drops	cloudy	clear	356	350
399 ppm	a	cloudy, ice 2	clear, many small drops	cloudy, ice 2	clear, many small drops	cloudy	clear	346	321
508 ppm	b	b	b	cloudy, ice 3	clear, many small drops	cloudy	light haze	446	443
614 ppm	b	b	b	cloudy, ice 3	clear, many small drops	cloudy	medium haze	478	449
706 ppm	b	b	b	cloudy, ice 3	clear, many small drops	cloudy	heavy haze	560	588
853 ppm	b	b	b	cloudy, ice 3	cloudy/ water	cloudy	cloudy	729	742
1002 ppm	a	cloudy, ice 3	cloudy/ water	cloudy, ice 3	cloudy/ water	cloudy	cloudy	771	750
2105 ppm	a	cloudy, ice 4	cloudy/ water	c	c	c	cloudy	1830	1930
4166 ppm	a	cloudy, ice 6	cloudy/ water	c	c	c	cloudy/ water	d	d
10799 ppm	a	cloudy, ice 6	cloudy/ water	c	c	c	cloudy/ water	d	d

a = not recorded b = sample was not prepared c = Sample not continued d = sample not determined

3 to 6 = coating with formation of ice on bottom

AC98094/ws/a - 5

MIL-H-83282 Freezing and Warm-up Cycle Test

17-20 March 1997

Fluid Type MIL-H-	Theoretical Water (ppm)	Coulomatic Karl Fischer (ppm)	Initial Appearance of Fluid	2nd Day			3rd Day			4th Day		
				Viscosity	Appearance at		Viscosity	Appearance at		Viscosity	Appearance at	
				at -40°C	-40°C	Room	at -40°C	-40°C	Room	at -40°C	-40°C	Room
83282	Original	38	Clear	2107	Clear	Clear	2099	Clear	Clear	2102	Clear	Clear
83282	448	386	Clear	2091	Cloudy	Clear	2080	Cloudy	Clear	2091	Clear	Clear
83282	561	233	Clear	2103	Cloudy	Clear	2090	Cloudy	Clear	2102	Clear	Clear
83282	697	597	Clear	2095	Cloudy	Clear	2094	Cloudy	Clear	2087	Clear	Clear

The test samples were prepared from MLSS 97-17 (MIL-H-83282 hydraulic fluid) by the addition of water..
Samples were placed in a ultrasonic water bath for 1 hour and then shaken to mix the water.

Part of the samples were placed in Kinematic viscometers and then in a -40°C low temperature bath overnight before determining their viscosities. The remaining test samples were analyzed for water content.

The analysis to determine the water content for the theoretical 561 and 697 ppm could have been off because of free water adhering to the glass walls of the test tubes. In the theoretical 448 ppm sample the water dots were not visible.

MIL-H-87257 Freezing and Warm-up Cycle Test

26-29 Jan 1998

Theoretical Water (ppm)	Initial Appearance	2nd Day		3rd Day		4th Day		K-F Determination of Water (ppm)
		-40°C	Room Temp	-40°C	Room Temp	-40°C	Room Temp	
MLSS 97-39	Clear	Clear	Clear	Clear	Clear	Clear	Clear	106
384 ppm	Clear	Lt. Haze/ ice	Clear / water	Cloudy	Clear	Haze	Clear	398
574 ppm	Clear	Cloudy / ice	Clear / water	Cloudy	Very Lt Haze	Cloudy	Clear	561
643 ppm	Clear	Cloudy / ice	Clear / water	Cloudy / ice	Lt Haze	Cloudy/ ice	Very Lt Haze	631
748 ppm	Lt Haze	Cloudy / ice	Lt. Haze	Cloudy	Haze	Cloudy	Lt. Haze	686
861 ppm	Cloudy	Cloudy / ice	Cloudy	Cloudy / ice	Cloudy	Cloudy / ice	Haze	821
1199 ppm	Cloudy	Cloudy / ice	Cloudy	Cloudy / ice	Cloudy	Cloudy / ice	Cloudy	1162

Samples were prepared with MLSS 97-39 a blend of MIL-H-87257 hydraulic fluids.
The original MLSS 97-39 sample contained 103 ppm of water.
In the above hydraulic fluids the addition of water separates and falls to the bottom of the test tubes.
The samples were placed in a sonic bath for 1 hour and then mixed with the use of a vortex stirrer.
The initial appearance will be referred to as the observed fluid appearance after the first mixing.
The cyclic testing includes the mixing then overnight at -40°C observation and a warm-up observation.

Coulomatic Karl Fischer method was used to determine the water content in the above samples after testing.

MIL-H-87257 Freezing and Warm-up Cycle Test

9-12 Feb 1998

Theoretical Water (ppm)	Initial Appearance	2nd Day		3rd Day		4th Day		K-F Determination of Water (ppm)
		-40°C	Room Temp	-40°C	Room Temp	-40°C	Room Temp	
MLSS 97-39	Clear	Clear	Clear	Clear	Clear	Clear	Clear	104
295 ppm	Clear	Med. haze	Clear	Lt. haze	Clear	Lt. haze	Clear	317
353 ppm	Clear	Cloudy	Clear	Med. haze	Clear	Med. haze	Clear, water	361
423 ppm	Clear, water	Cloudy, ice	Clear, water	Cloudy	Clear, water	Cloudy	Clear, water	410
451 ppm	Clear, water	Med. Haze, ice	Clear, water	Cloudy, ice	Clear, water	Cloudy	Clear, water	434
577 ppm	Lt haze	Cloudy	Lt. haze	Cloudy, ice	Clear, water	Cloudy	Clear, water	466
735 ppm	Clear, water	Lt. Haze, ice	Clear, water	Cloudy, ice	Haze	Cloudy	Med. haze	652
960 ppm	Clear, water	Med. Haze, ice	Clear, water	Cloudy, ice	Clear, water	Cloudy	Cloudy	860
1024 ppm	Clear, water	Cloudy, ice	Clear, water	Cloudy, ice	Clear, water	Cloudy, ice	Med. haze, water	758

Samples were prepared with MLSS 97-39 a blend of MIL-H-87257 hydraulic fluids.
The original MLSS 97-39 sample contained 103 ppm of water.
In the above hydraulic fluids the addition of water separates and falls to the bottom of the test tubes.
The samples were placed in a sonic bath for 1 hour and then mixed with the use of a vortex stirrer.
The initial appearance will be referred to as the observed fluid appearance after the first mixing.
The cyclic testing includes the mixing then overnight at -40°C observation and a warm-up observation.
Coulomatic Karl Fischer method was used to determine the water content in the above samples after testing.

MIL-H-87257 Freezing and Warm-up Cycle Test

29 Sept - 2 Oct 1997

Fluid Type MIL-H-	Theoretical Water (ppm)	Coulomatic Karl Fischer (ppm)	Initial Appearance of Fluid	2nd Day			3rd Day			4th Day		
				Viscosity at -40°C	Appearance at -40°C	Appearance at Room	Viscosity at -40°C	Appearance at -40°C	Appearance at Room	Viscosity at -40°C	Appearance at -40°C	Appearance at Room
87257	Original	115	Clear	493	Clear	Clear	493	Clear	Clear	493	Clear	Clear
87257	660	595	Lt. Cloudy	492	Lt. Cloudy	Clear	490	Clear	Clear	494	Clear	Clear
87257	898	685	Cloudy	492	Cloudy	Lt. Haze	493	Lt. Haze	Clear	491	Clear	Clear
87257	1288	1081	Cloudy	493	Cloudy	Cloudy	492	Cloudy	Haze	491	Cloudy	Haze

The MLSS 97-39 sample was prepared by blending several MIL-H-87257 hydraulic fluids from different manufactures.
The test samples were prepared from the MLSS 97-39 by the addition of water.

The test samples were placed in a ultrasonic water bath for 1 hour. A Maxi Mix II was then used to create a vortex mixing of the samples.
The vortex mixing action appears to be superior to hand shaking the samples.

Part of the prepared samples were placed in Kinematic viscometers and then in a -40°C cold temperature bath over night.
The remaining test samples were analyzed for water content.

MIL-H-5606 Freezing and Warm-up Cycle Test

17-20 March 1998

Theoretical Water (ppm)	Initial Appearance	2nd Day		3rd Day		4th Day		K-F Determination of Water (ppm)	
		-40°C	Room Temp	-40°C	Room Temp	-40°C	Room Temp	Run 1	Run 2
212 ppm	Clear	Light Haze	Clear	Clear	Clear	Clear	Clear	155	162
477 ppm	Clear	Med. Haze fine floating ice	Light Haze water drops	Med. Haze	Light Haze	Light Haze floating particles	Light Haze fine water dots	310	312
610 ppm	Light Haze	Cloudy, ice	Heavy Haze Fine water dots	Cloudy floating particles	Med. Haze Fine water dots	Light Haze floating particles	Med. Haze water dots	386	388
725 ppm	Cloudy	Cloudy, fine ice particles	Cloudy Fine water dots	Cloudy floating particles	Heavy Haze water drops	Cloudy floating particles	Med. Haze water dots	396	402
927 ppm	Light Haze fine dots of water	Cloudy, fine ice particles	Heavy Haze Fine water dots	Cloudy floating particles	Cloudy water drops	Cloudy floating particles	Cloudy water dots	753	794
1351 ppm	Heavy Haze fine dots of water	Cloudy, fine ice particles	Cloudy Fine water dots	Cloudy floating particles	Cloudy water drops	Cloudy floating particles	Cloudy water dots	1252	1249

Coulomatic Karl Fischer method was used to determine the water content in the above samples.
MLSS 94-71 (MIL-H-5606) hydraulic fluid was used to prepare the above samples.
The MLSS 94-71 had a 34 ppm water content.

MIL-H-5606 Freezing and Warm-up Cycle Test

6-9 Oct 1997

Fluid Type MIL-H-	Theoretical Water (ppm)	Coulomatic Karl Fischer (ppm)	Initial Appearance of Fluid	2nd Day			3rd Day			4th Day		
				Viscosity at -40°C	Appearance at -40°C	Appearance at Room	Viscosity at -40°C	Appearance at -40°C	Appearance at Room	Viscosity at -40°C	Appearance at -40°C	Appearance at Room
5606	Original	70	Clear	466	Clear	Clear	466	Clear	Clear	462	Clear	Clear
5606	241	233	Clear	466	Clear, (1)	Clear	467	Clear	Clear	464	Clear	Clear
5606	456	406	Lt. Haze	470	Lt. Haze, (1)	Clear	468	Lt. Haze	Clear	464	Clear	Clear
5606	732	620	Cloudy	472	Cloudy	Lt. Haze	470	Cloudy	Lt. Haze	466	Lt. Haze	Clear

(1) = The fluid had a small ice crystal in the fluid.

Test samples were prepared from the MLSS 94-71 (MIL-H-5606 hydrauluic fluid) by the addition of water.
A Maxi Mix II was then used to create a vortex mixing of the samples. The samples were heated to 34° in a water bath and then mixed..

Part of the prepared samples were placed in Kinematic viscometers and then in a -40°C cold temperature bath over night.
The remaining test samples were analyzed for water content.

MIL-H-5606 Freezing and Warm-up Cycle Test

2-5 March 1998

Theoretical Water (ppm)	Initial Appearance	2nd Day		3rd Day		4th Day		K-F Water Determination (ppm)
		-40°C	Room Temp	-40°C	Room Temp	-40°C	Room Temp	
Original	Clear	Clear	Clear	Clear	Clear	Clear	Clear	57
50 ppm	Clear	Lt. Haze	Clear	Clear	Clear	Lt. Haze	Clear	94
174 ppm	Clear	Lt. Haze	Clear, water	Lt. Haze	Clear	Lt. Haze	Clear	136
207 ppm	Clear	Lt Haze	Clear	Lt. Haze	Clear	Lt. Haxe	Clear	171
350 ppm	Lt. Haze	Haze, ice	Lt Haze	Haze	Lt. Haze, water	Med. Haze	Lt Haze, water	259
439 ppm	Haze	Cloudy	Haze	Cloudy	Haze, water	Haze, ice	Haze, water	312
535 ppm	Cloudy, water	Cloudy, ice	Cloudy	Cloudy, ice	Cloudy, water	Cloudy, ice	Cloudy, water	424

Coulomatic Karl Fischer method was used to determine the water content at the end of the test period.
MLSS 94-71 (MIL-H-5606) hydraulic fluid was used to prepare the above samples.
The MLSS 94-71 before the above cycling testing had a 47 ppm water content.

Recommended Water Limits

MIL-H-5606	150 - 200 ppm
MIL-H-83282	350 - 400 ppm
MIL-H-87257	300 - 350 ppm

These tests were run at atmospheric pressure.
Pressure reduces the freezing point of water.

Hydraulic Fluid Purification

Pump Tests with Purified Hydraulic Fluid

C. Ed Snyder and Shashi Sharma

Materials and Manufacturing Directorate
Air Force Research Laboratory, WPAFB

Hydraulic Fluid Purification

Cleaning Effectiveness of Purifiers

- Easy to Check
    - Measure
        - Particulate Contamination
        - Moisture
        - Chlorinated Solvents
        - Other
- Lots of Experience

Hydraulic Fluid Purification

Performance Capabilities of Purified Fluid - Different Matter

- How Do We Know Purified Fluid Will Work as Well as New Fluid ?
    - Run Fluid Specification Tests ?
        - Spec Tests Developed To Assure Acceptable Performance of <u>New</u> Hydraulic Fluid
        - In New Fluid Development Programs, Hydraulic Pump Performance Tests are Required
        - Should Purified Fluid Be Considered a New Fluid?

Hydraulic Fluid Purification

What Types of Spec Tests Should Be Conducted ?

- Fluid Cleanliness Tests
  - Particulate, Moisture & Chlorinated Solvent
- Checks for Additive Depletion
  - Stability
  - Lubricity
  - Foaming
- Checks for Unremoved Contaminants
  - Lube oil, O-ring assembly aid (grease), etc.

Hydraulic Fluid Purification

Problem with Spec Tests - Look at Each Property Individually

- Hydraulic Systems Require Properties to Be Optimized Simultaneously

- Hydraulic Component/System Tests are the Only Way to Simulate the Performance Demands of the Aircraft Hydraulic System

- The Hydraulic Pump Test Has Proven to Be the Most Strenuous, but Doable Component Test to Validate the Performance of Hydraulic Fluids

Hydraulic Fluid Purification

AFRL/MLBT Has Pump Testing Facility

- Designed Specifically for Fluid Validation Testing
  - Small Fluid Volume
  - Fluid Sampling Capability
  - Well Instrumented
- Extensive Experience with Wide Variety of Hydraulic Fluids and Several Pumps

Hydraulic Fluid Purification

Question of Fluid History Raised

- Where Did Fluid Come From ?
- How Many Hours ?
- When/ How Much New Fluid Added to System ?
- How Many Cycles Through Purifier ?

One Solution - Run Controlled Fluid Purification and Fluid Quality Verification at ML

Hydraulic Fluid Purification

Summary

- It is Important to Verify Fluid Quality as Well as Fluid Cleanliness
- While Property Tests in the Spec Can be Informative, *Pump Testing* (or Other Component/System Testing) is Required to Assure Acceptable Performance of a Fluid in a System

Pump Tests with Purified MIL-H-5606

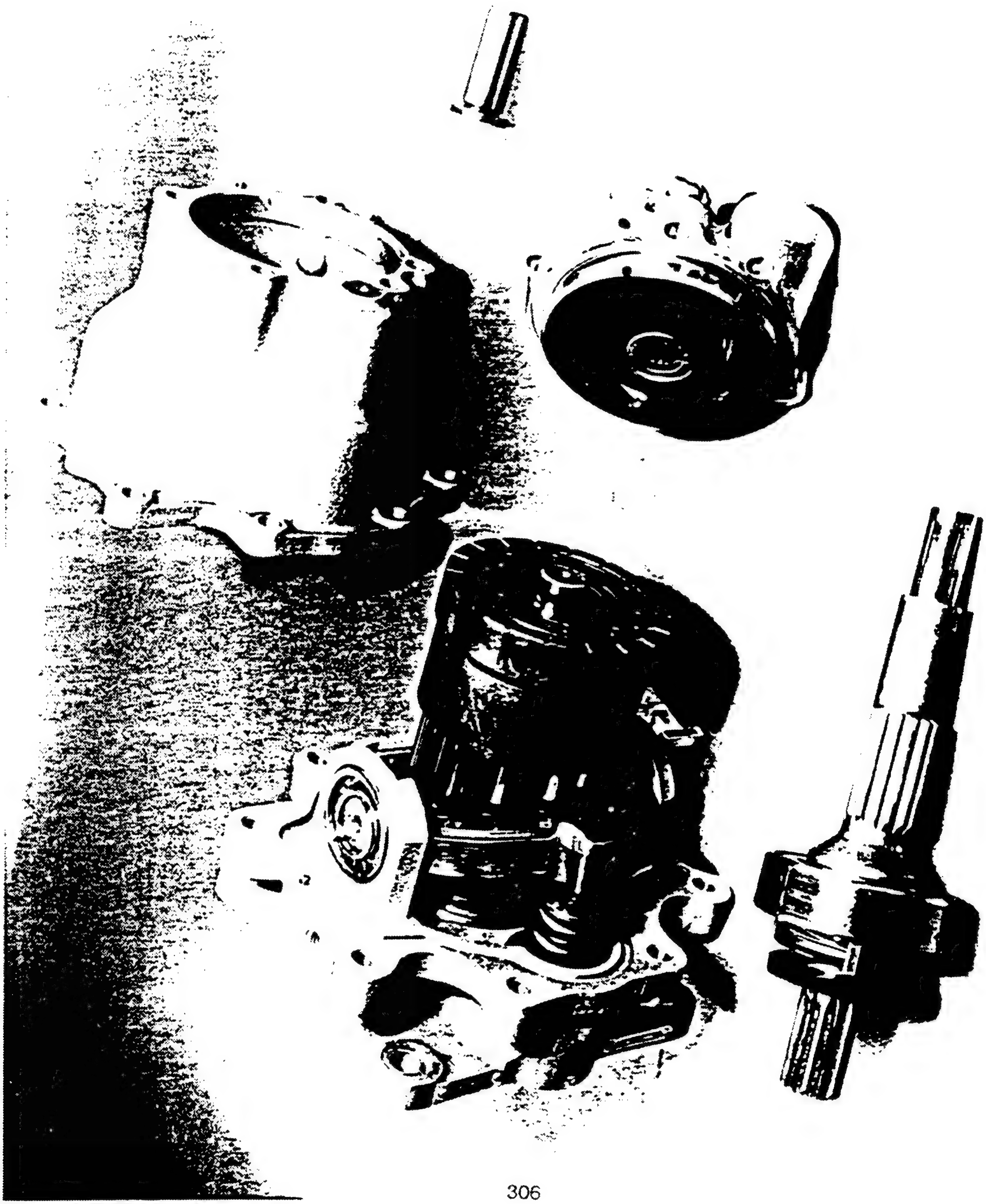
Pump Test Objective

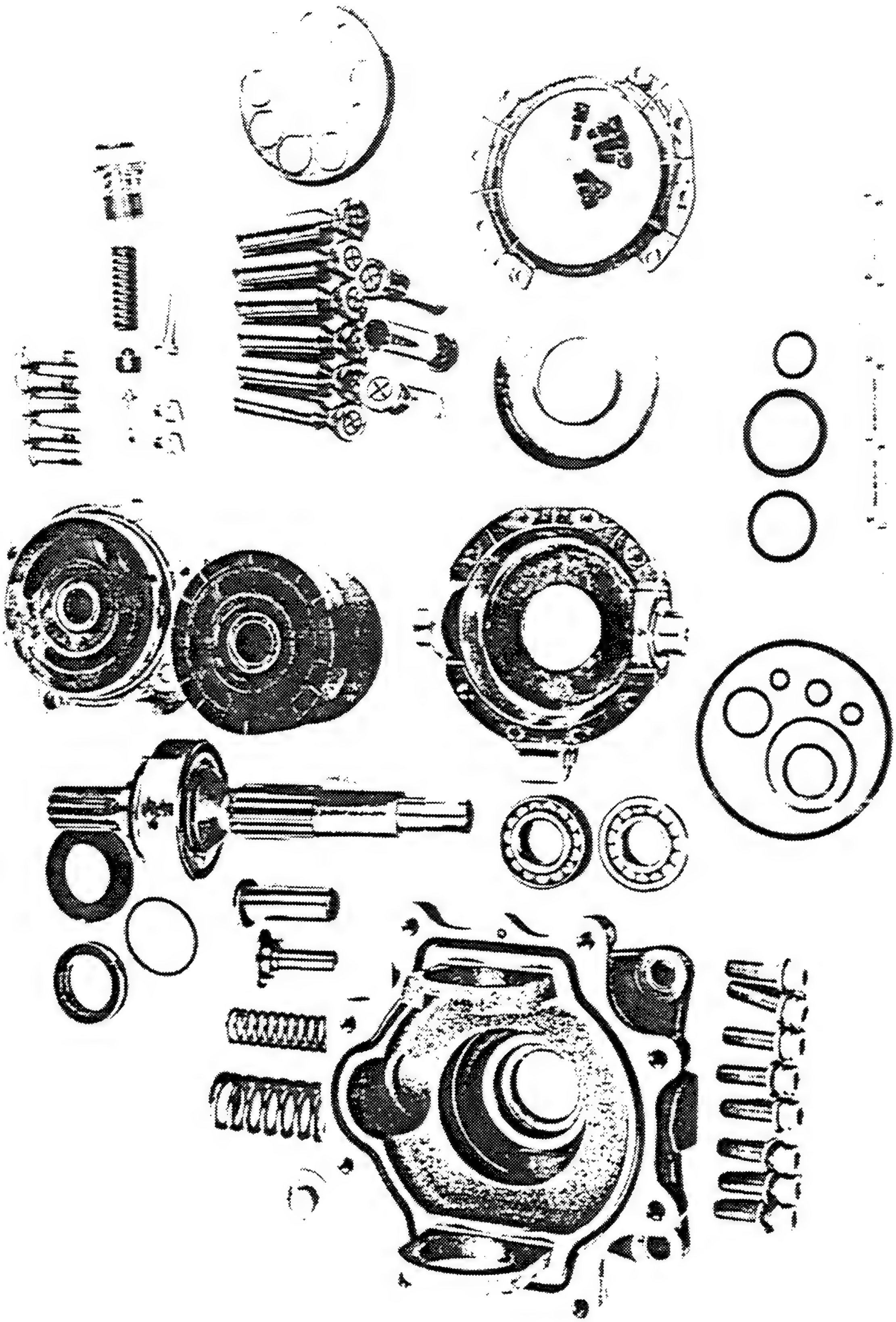
Does the Fluid Purification Adversely Affect Pump Life?

Pump Tests with Purified MIL-H-5606

Test Plan

- *Test 1: Base Line with MIL-H-5606*
  - Vickers Pump PV3-075-15
  - 1000 Hr Inspection
  - 1500 Hours or Performance Degradation
  - 5000 rpm, 3000 psig, 255°F Max Fluid Temp
  - Flow Cycled Between 12 gpm and 3 gpm Every Minute
  - Periodic Fluid Samples
- *Test 2: Test with Purified MIL-H-5606*
  - Same as Test 1 Except Fluid Purification
  - Fluid Purified using Pall Purifier Every 200 Hours





Pump Tests with Purified MIL-H-5606

Lubrication Regimes

- *Boundary Lubrication*
  - Gross Metal-Metal Contact
  - Lower Entraining Speeds
  - Influenced by the Chemistry of the Lubricant and Material Properties of the Surfaces
  - Anti-Wear Additives and Surface Modifications Help
- *Fluid Film Lubrication*
  - Film Thickness Large Compared to Surface Roughness
  - No (or rare) Metal-Metal Contacts
  - Film Thickness and Power Losses Affected By
    - » Viscosity of the Lubricant
    - » Pressure-Viscosity Effects

Pump Tests with Purified MIL-H-5606

Surfaces Under Boundary Lubrication

- » Actuator Piston
- » Shaft and Cylinder Block Splines
- » Pintle Bearings

– Following Rotating/Sliding Interfaces at Slower Speeds
- » Cylinder Block and Valve Plate Faces
- » Piston Shoe Faces and Piston
- » Pistons and Cylinder Bores
- » Hold Down Plate and Bearing Plate
- » Main Thrust Ball Bearing and Needle Bearing

• *Surfaces Under Fluid Film Lubrication*

– Following Rotating/Sliding Interfaces at Higher Speeds
- » Piston Shoe Ball Joints
- » Cylinder Block and Valve Plate Faces
- » Piston Shoe Faces and Piston
- » Pistons and Cylinder Bores
- » Hold Down Plate and Bearing Plate
- » Main Thrust Ball Bearing and Needle Bearing

Pump Tests with Purified MIL-H-5606

Test Stand

- All Stainless Steel
- Capable of 8000 psig and 350°F
- Test Loop Volume ~ 8 Gallon
- Instrumented to Operate Unattended

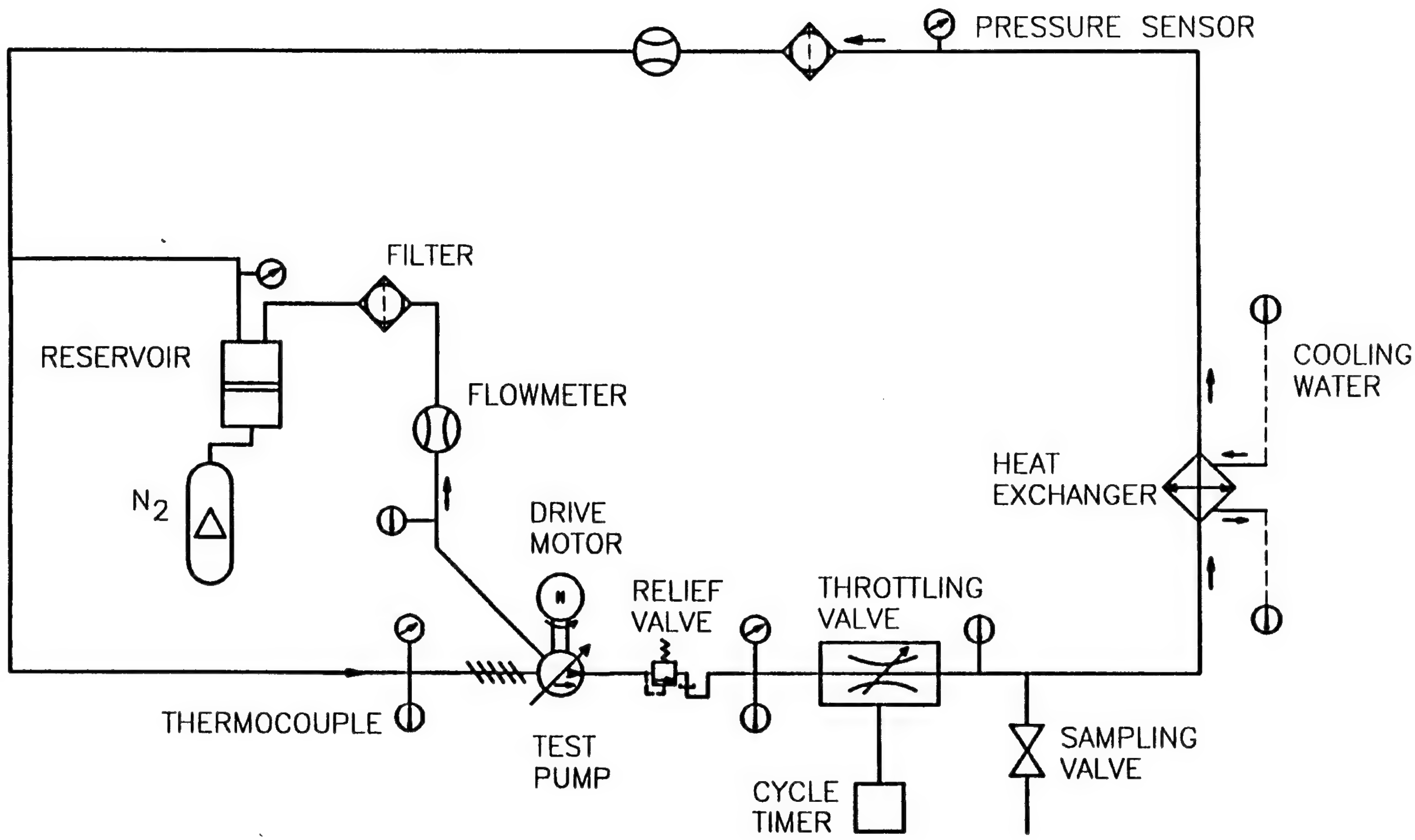


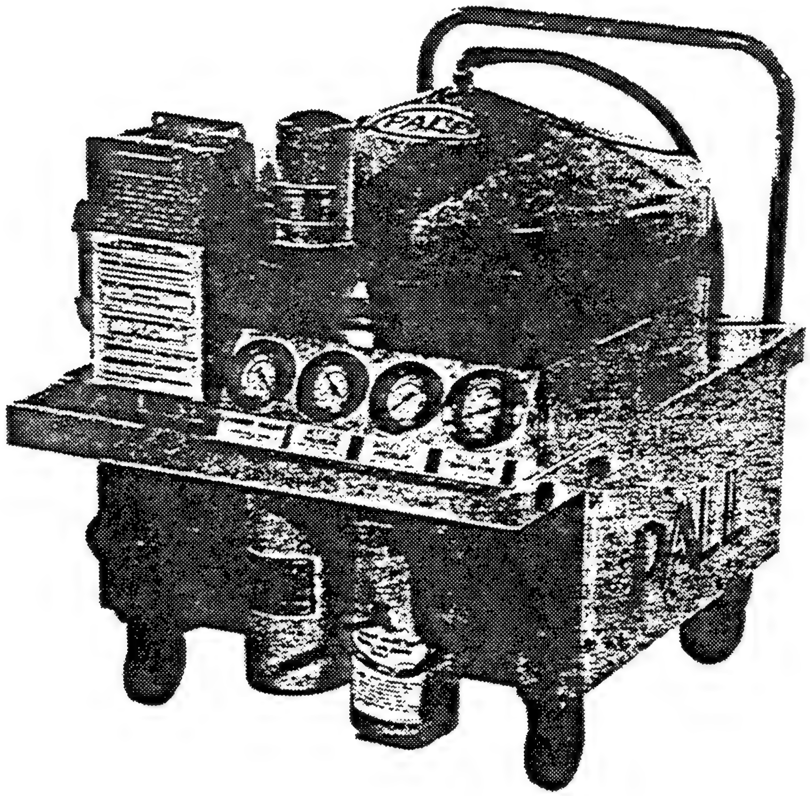
FIGURE 1: HYDRAULIC PUMP TEST CIRCUIT

Pump Tests with Purified MIL-H-5606

Purifier

- Pall Model PE-00440-1H
  - Max Inlet Fluid Temperature: 145°F
  - Fluid Circulation: 3 gpm
  - Operating Viscosity: 1300 SSU
  - Discharge Pressure: 70 psig
  - Inlet Pressure (Max): 20 psig
  - Inlet Pressure (Min): 10" Hg
  - Dimensions: 34"H x 27.5" W x 34" L

THE PLM PORTABLE FLUID PURIFIER



Automatic Removal of Particulate, Water, Air and Chlorinated Solvent Contamination from Fluid Systems to Increase Equipment Reliability and Performance

PALL

Pall Land and Marine Corporation
A Subsidiary of Pall Corporation

Pump Tests with Purified MIL-H-5606

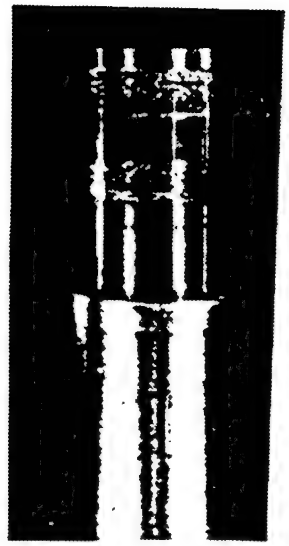
Test 1 Results: Base Line with MIL-H-5606

- Disassembly at 972 Hours showed
  - Spalling on the Shaft (Needle Bearing End)
  - Some Erosion on Cylinder Block and Shoe Faces
- Successfully Completed 1500 Hours
  - Spalling on the Shaft Did Not Affect Performance
  - Additional Erosion on Cylinder Block and Shoe Faces
- Case Drain Flow Increased With Time
- Viscosity of Fluid Decreased With Time

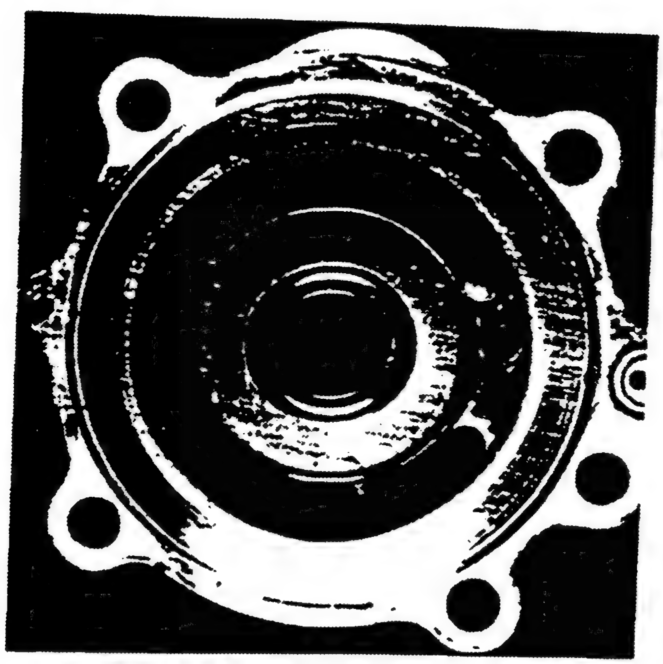
Pump Tests with Purified MIL-H-5606

Test 2 Results: With Purified MIL-H-5606

- Disassembly at 972 Hours showed
  - No Spalling on the Shaft
  - Erosion on Cylinder Block Face
  - Erosion on Shoe Faces More Than Test 1
- Successfully Completed 1500 Hours
  - No Spalling on the Shaft
  - Additional Erosion on Cylinder Block and Shoe Faces
- Case Drain Flow Increased With Time
- Viscosity of Fluid Decreased With Time

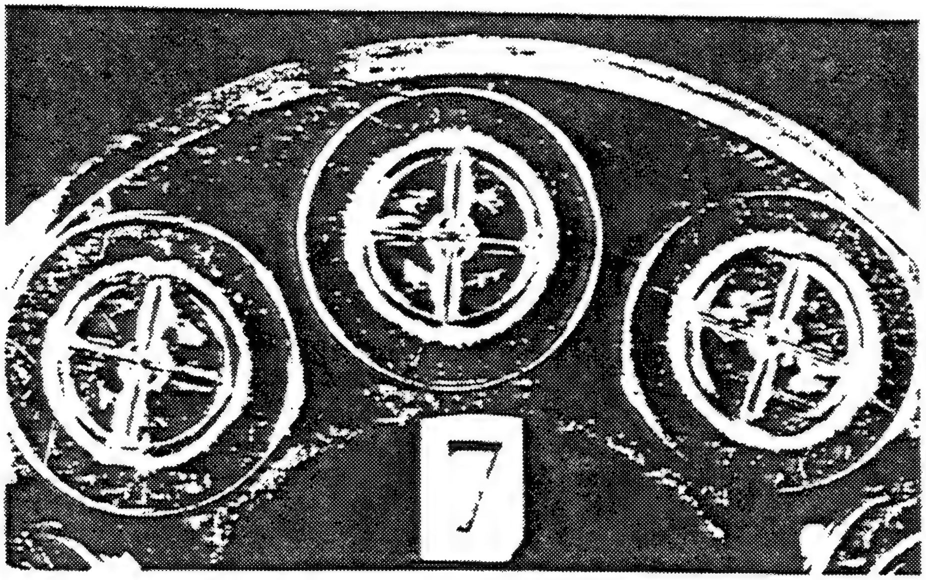


Pump Shaft

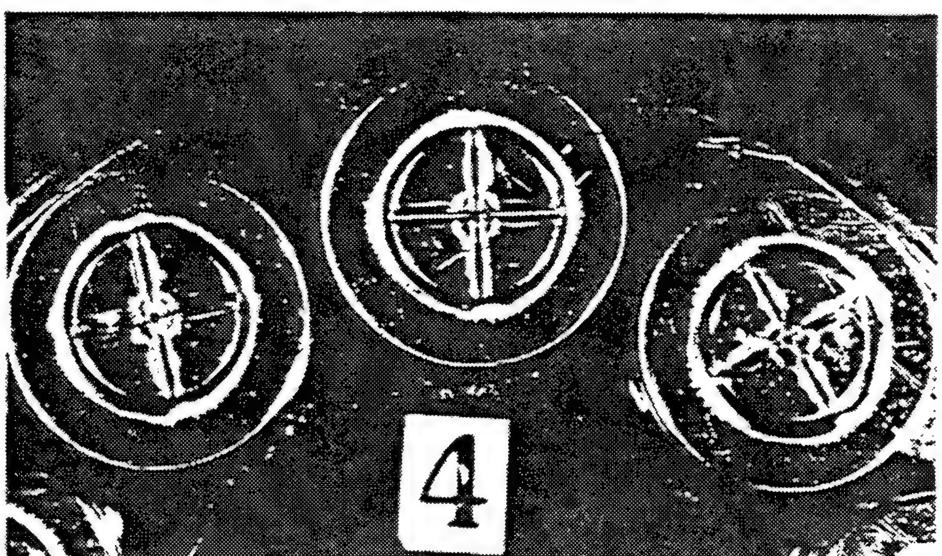


Valve Plate

Pump Shaft and Valve Plate after 972 Hours
Pump Test 35 with MIL-H-5606

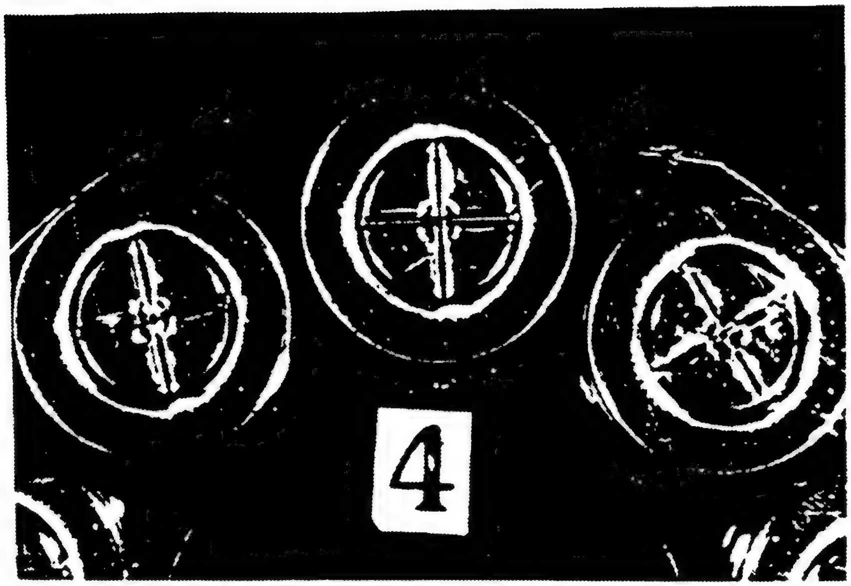


Enlargement of Piston Shoe Faces 6,7,8

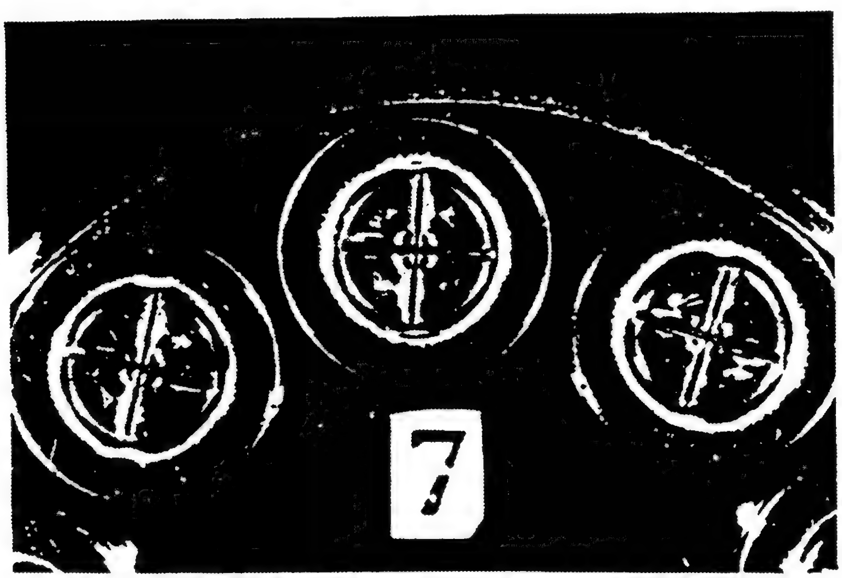


Enlargement of Piston Shoe Faces 3,4,5

Piston Shoe Faces after 1500 Hours
Pump Test 35 with MIL-H-5606

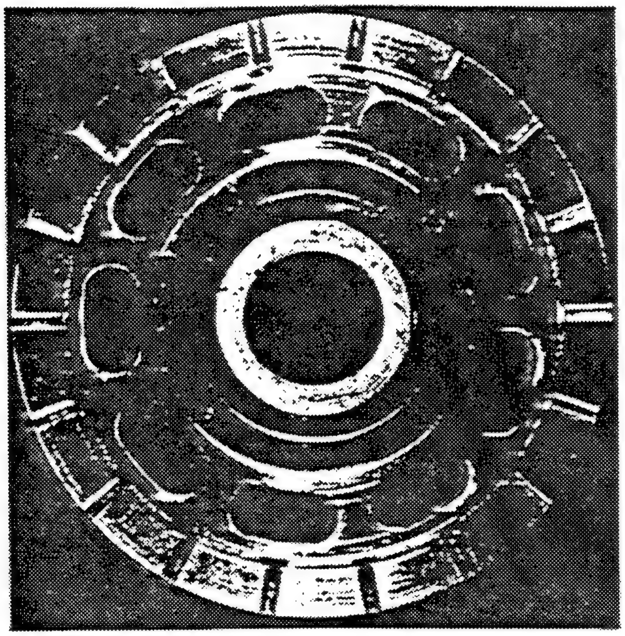


Enlargement of Piston Shoe Faces 3,4,5

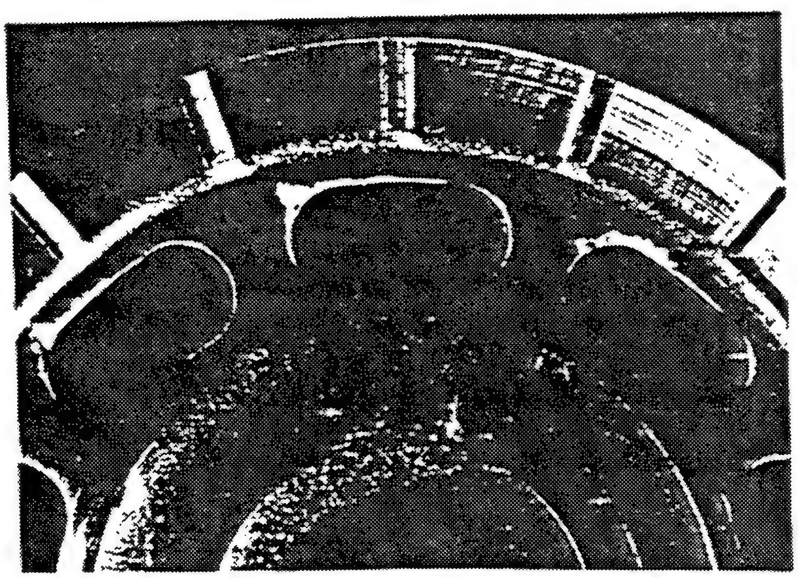


Enlargement of Piston Shoe Faces 6,7,8

Piston Shoe Faces after 972 Hours
Pump Test 35 with MIL-H-5606

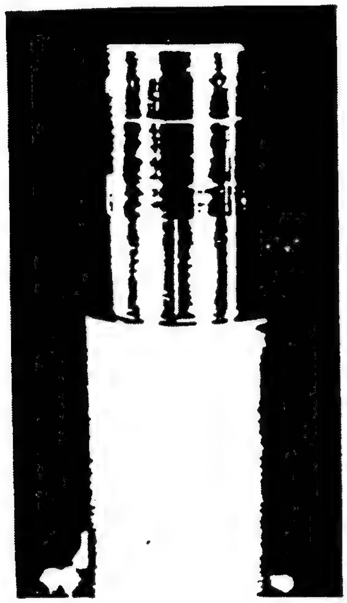


Cylinder Block Face

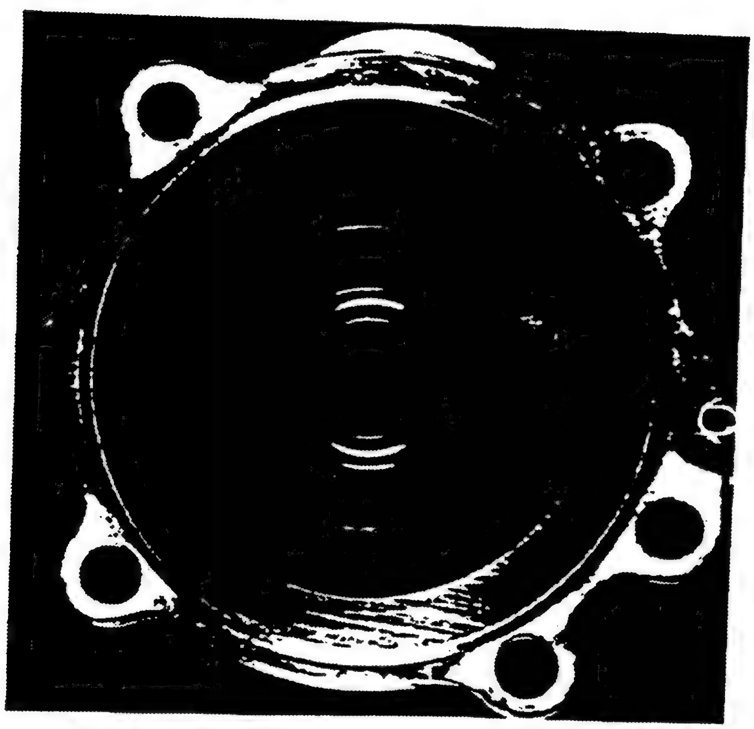


Enlargement of Cylinder Block Face

Cylinder Block Faces after 972 Hours
Pump Test 35 with MIL-H-5606

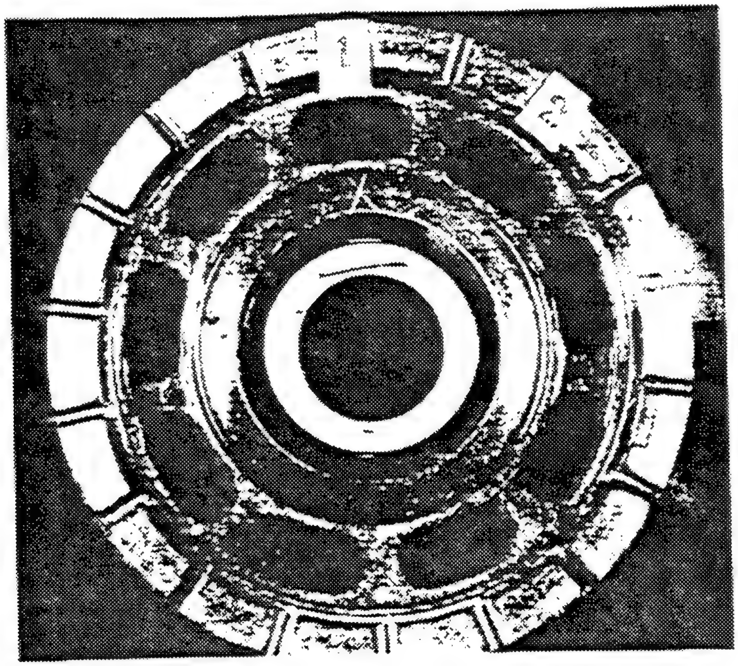


Pump Shaft

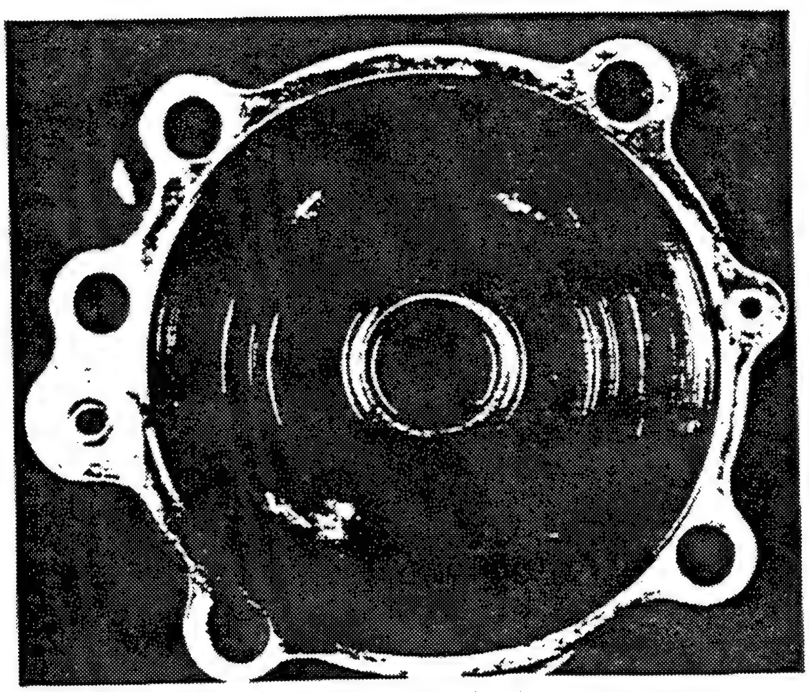


Valve Plate

Cylinder Block Faces after 1500 Hours
Pump Test 35 with MIL-H-5606

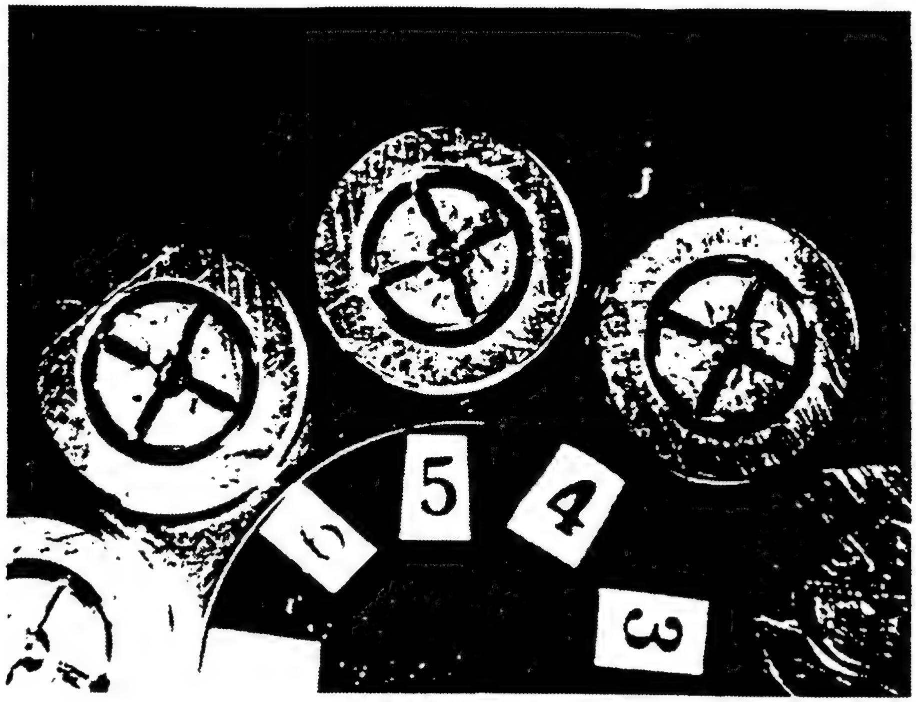


Cylinder Block Face

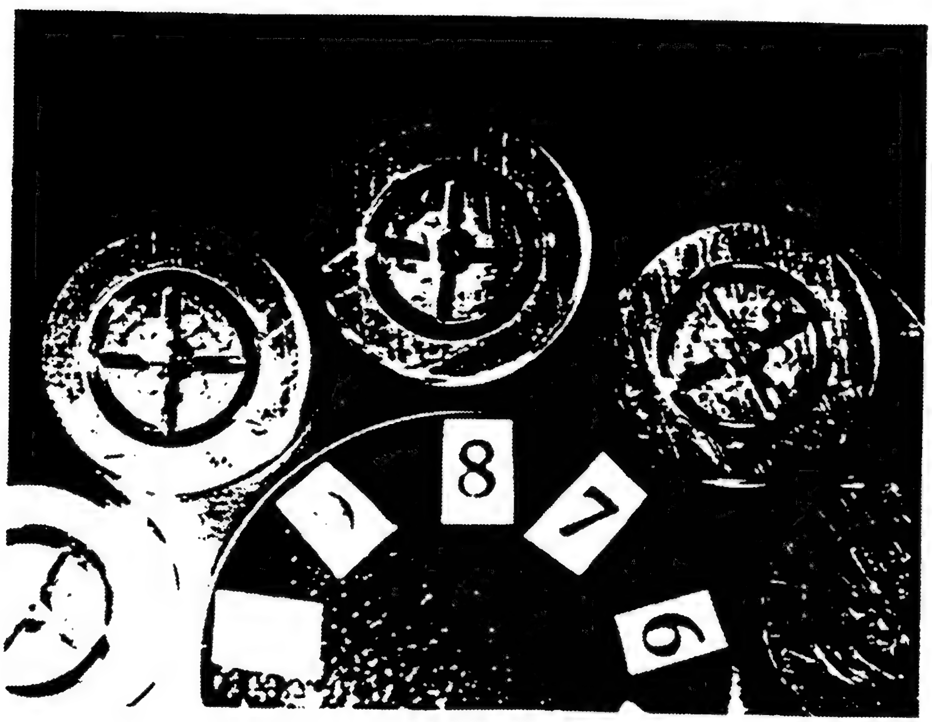


Cylinder Block Plate

Cylinder Block Face and Plate after 972 hrs.
Pump Test 36 with MIL-H-5606



Piston Shoe Faces 4,5,6



Piston Shoe Faces 7,8,9

Piston Shoe Faces after 972 hrs.
Pump Test 36 with MIL-H-5606

Pump Tests with Purified MIL-H-5606

Analyses of Fluid Samples

- Viscosity
- Water Content
- Lubricity (4 Ball Wear Test)
- Foaming
- Metal Analysis
- Gas Chromatography

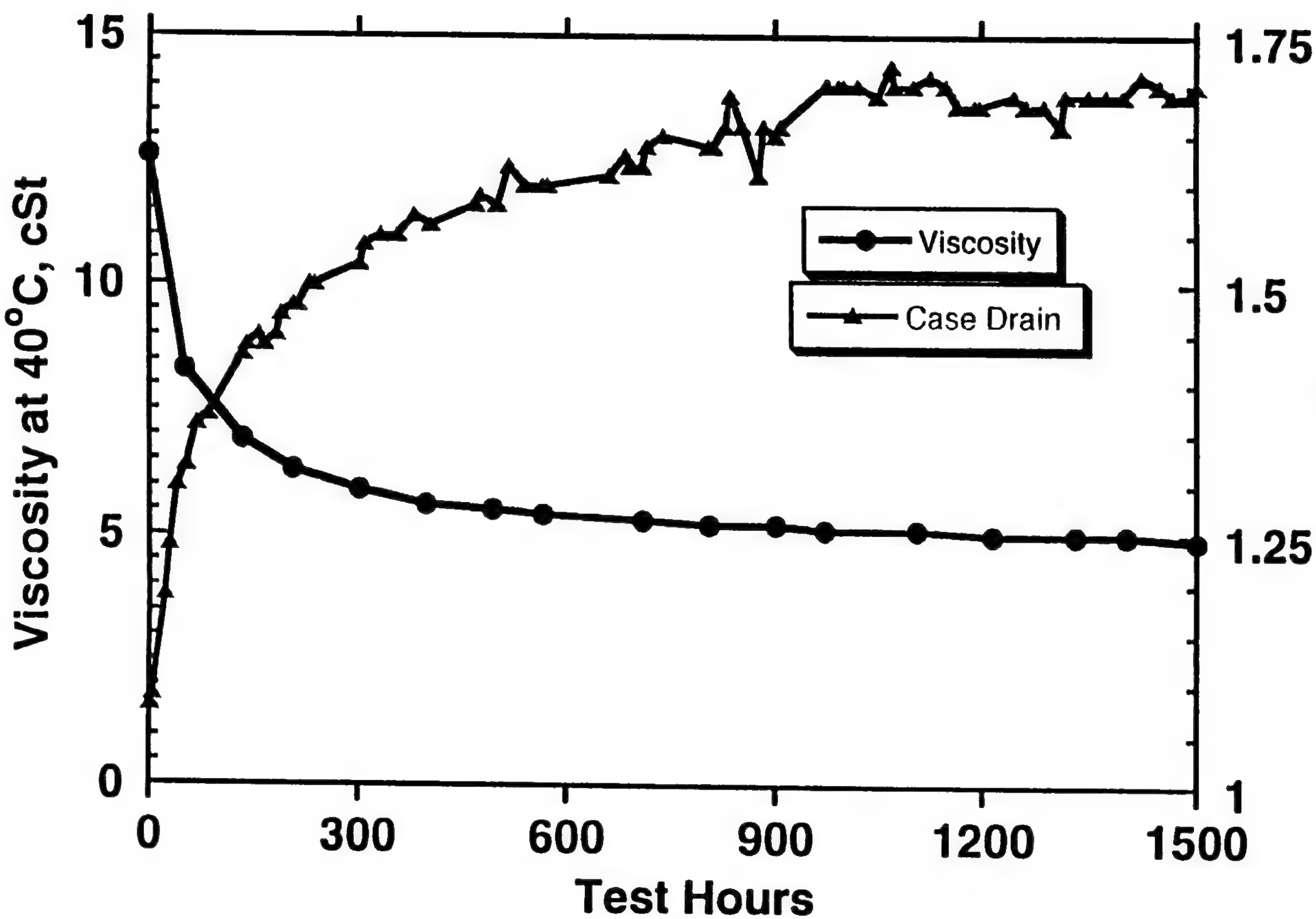


Fig. 2. Case Drain Flow and Viscosity - Test 35 Base Line with MIL-H-5606

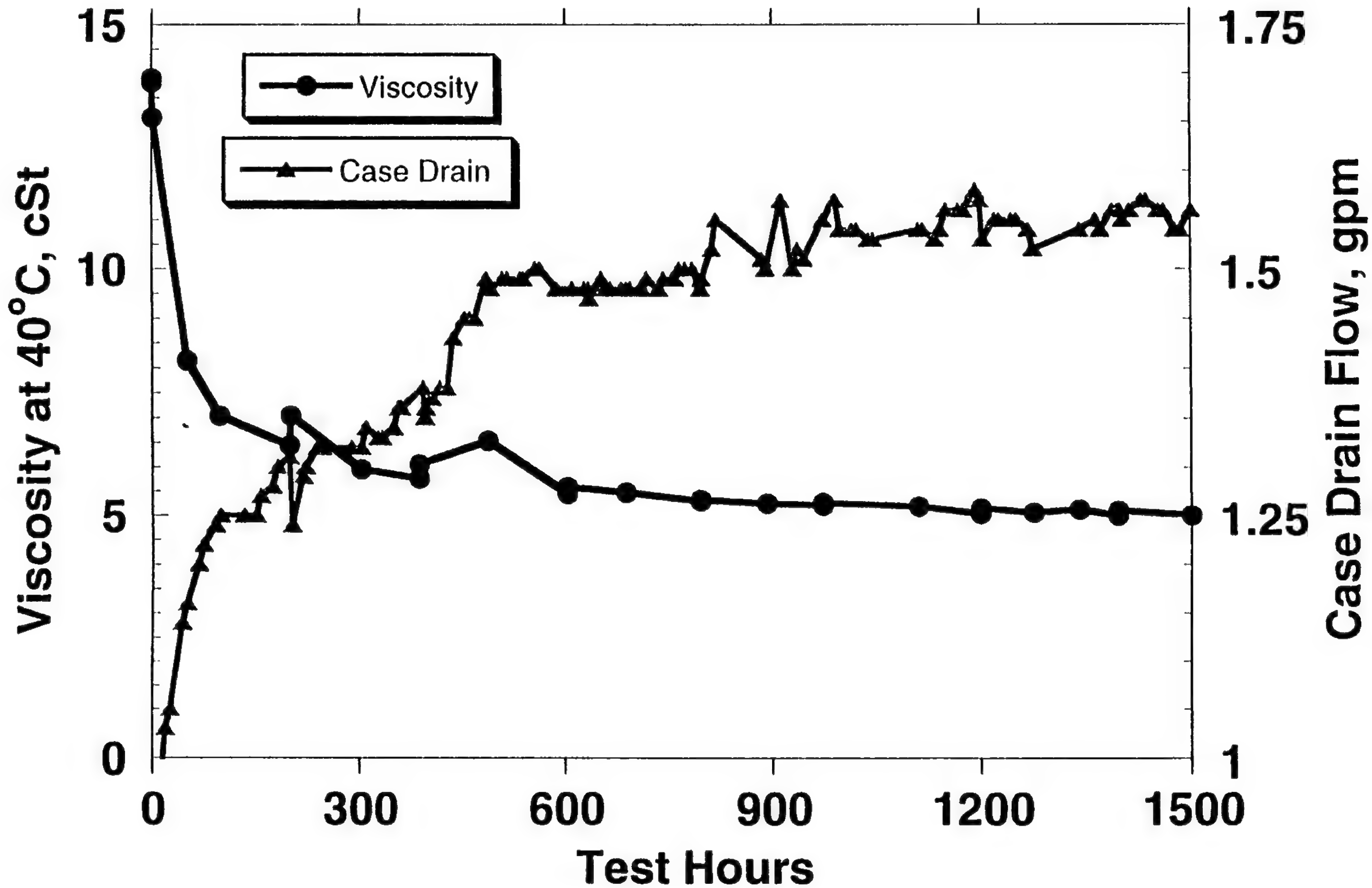


Fig. 3. Case Drain Flow and Viscosity - Test 36 with Purified Mil-H-5606

Pump Tests with Purified MIL-H-5606

Conclusion

- 1500 Hour Pump Tests Completed with
  - MIL-H-5606 and
  - Purified MIL-H-5606
- No Significant Difference Between the Two Tests
- Significant Reduction in Viscosity in Both Tests
- Increased Case Drain Flow in Both Tests Due to Reduction in Viscosity and *Not* Due to Increased Wear
- *Purification of MIL-H-5606 Did Not Adversely Affect Pump Life*

Pump Tests with Purified MIL-PRF-83282

Test Plan

- *Test 1: Base Line with MIL-PRF-83282*
  - Vickers Pump AP12V-17
  - 1000 Hr Inspection
  - 2000 Hours or Performance Degradation
  - 5800 rpm, 3100 psig, 255°F Max Fluid Temp
  - Flow Cycled Between 28 gpm and 36 gpm Every Minute
  - Periodic Fluid Samples
- *Test 2: Test with Purified MIL- PRF-83282*
  - Same as Test 1 Except Fluid Purification
  - Fluid Purified using Pall Purifier Every 300 Hours

Pump Tests with Purified MIL-PRF-83282

Test Stand Modifications

- New Data Acquisition System
- Circuit Augmented For Higher Flow Rates

Progress

- Base Line Test With MIL-PRF-83282 at Midpoint Inspection

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33D FLIGHT TEST SQUADRON

IN GOD WE TRUST

ALL ELSE WE TEST

LOGISTICS FLIGHT

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33D FLIGHT TEST SQUADRON

"Enhancing Mobility Through Responsive Operational Test and Evaluation"

OVERVIEW

Each major command has separate test agencies that perform command-specific operational testing to ensure a new system or pieces of equipment meets the user's requirements. The 33d Flight Test Squadron (33 FLTS) is the Air Mobility Command's (AMC) agency for operational test and evaluation on all AMC aircraft and systems. Located at Fort Dix, New Jersey, the 33 FLTS is a squadron within the Air Mobility Warfare Center (AMWC), AMC's centralized education, training, and test organization. The 33 FLTS provides AMC with centralized expertise for enhancing air mobility. Part of our mission is to ensure new systems and equipment perform "as advertised" and can be supported. New squadron personnel are selected from a broad spectrum of operational skills (e.g., aircrew, maintenance, transportation, electronic warfare, aeromedical, and communications) and are trained to form the nucleus of the test organization—the ***Test Director.***

ORGANIZATION

The 33 FLTS is an extension of HQ AMC and works directly for HQ AMWC/CC. The 33 FLTS maintains a close relationship with the Directorate of Test and Evaluation (HQ AMC/TE)—the focal point of testing within AMC. The 33 FLTS Commander, Operations Officer, and Commander's Secretary comprise the Command Section. The 33 FLTS has four flights (Logistics Flight, Mobility Flight, Systems Flight, and Operations Support Flight), a Detachment (DET 1) at Charleston AFB SC, and five operating locations (Natick MA, Yuma AZ, Fort Lee VA, Fort Bragg NC, and Dobbins GA.).

LOGISTICS FLIGHT

The Logistics Flight (TEL) tests and evaluates the operational effectiveness and logistical suitability of new and/or modified aircraft systems and support equipment. They determine if the equipment meets the user's requirements and how well it meets those requirements. This is done by evaluating the system's reliability, maintainability, and availability. In addition, each new or modified system is evaluated based on the elements of logistics: design interface; support equipment; supply support; packaging, handling, storage, and transportation; computer resources; technical data; manpower and personnel; maintenance planning; training; and facilities. Although TEL's tests may take some time to accomplish, the data gained is vital in enabling decision-makers to make an informed acquisition decision.

WHY DO WE TEST?

Test and Evaluation (T&E) is a vital ingredient to the successful development, acquisition, and employment of a new or modified system. The primary purpose of T&E is the ***reduction of risk*** when fielding a new system. T&E reduces this risk by verifying the system meets or exceeds customer requirements. Operational Test and Evaluation (OT&E) is intended to test a new or modified system in a realistic environment to assess its operational effectiveness and suitability prior to fielding. The 33 FLTS ensures new ideas and developments meet the customer's needs, whether it's in the aircraft, maintenance shop, or anywhere in AMC. We test to find problems ***before*** the system is deemed "fully operational."

WHAT IS THE TEST PROCESS?

The test process evolves when a user's need is identified and approved—it can be a new weapon system, support equipment, avionics suite, or software upgrade. In AMC, the user writes a test request and sends it to HQ AMC/TE. HQ AMC/TE uses the test request to generate a test order, which in turn is sent to the 33 FLTS—this completes the formal tasking to begin testing. The Test Director then develops a test plan for execution. The test is complete when the final report is staffed and approved by HQ AMC. Test results are used to make procurement decisions on new and modified systems. Procedures to submit a test request can be found in AMCI 99-101.

LOGISTICS FLIGHT PERSONNEL

LOGISTICS FLIGHT COMMANDER

Lt Col Arnold Flores

Lt Col Flores has 16 years of aircraft maintenance experience on C-5, C-9, C-130, C-141, T-37, and T-38 aircraft. He has served as an Aircraft Maintenance Officer, 47th Flying Training Wing, Laughlin AFB TX; Commander, Detachment 219, 3754th Field Training Squadron, Dover AFB DE; Aircraft Maintenance Officer, 436th Military Airlift Wing, Dover AFB DE; Aircraft Maintenance Officer, 435th Tactical Airlift Wing, Rhein-Main AB GE; and as Commander, 624th Maintenance Squadron, Pope AFB NC. He received his Bachelor of Science Degree from the Air Force Academy and his Masters Degree from Wilmington College. He also holds a Department of Defense Level I certification in Acquisition Logistics and Test and Evaluation.

MAINTENANCE TEST DIRECTOR

Capt Phillip Greco

Capt Greco has 11 years of aircraft maintenance experience on C-5, C17, C-141, KC-10, and KC-135 aircraft. He has served as Communication and Navigation Shop OIC, and Guidance and Control Branch OIC, 437th Avionics Maintenance Squadron, Charleston AFB SC; Systems Branch OIC, 437th Field Maintenance Squadron, Charleston AFB SC; Maintenance Officer, 1680th (P) Airlift Control Element, Riyadh AB, Saudi Arabia; Green Aircraft Maintenance Unit OIC, 437th Aircraft Generation Squadron, Charleston AFB SC; and Maintenance Supervisor, 627th Air Mobility Support Squadron, RAF Mildenhall UK. He received his Bachelor of Arts from Vassar College and his Masters of Science from the University of Pennsylvania. He also holds a Department of Defense Level II certification in Acquisition Logistics, and Test and Evaluation.

TRANSPORTATION TEST DIRECTOR

Capt Howard Thomas

Capt Thomas has 7 years of transportation and logistics experience with the 463L Material Handling Equipment System. He has served as Air Terminal Operations Center Flight Commander; airfreight Flight Commander; Passenger Service Flight Commander; Combat Readiness Flight Commander; Vehicle Maintenance Flight Commander; and Vehicle Operations Flight Commander. Assignments include Columbus AFB MS, Minot AFB ND, McChord AFB WA, and Fort Dix NJ. He holds a Bachelor of Science Degree from the University of Missouri.

LOGISTICS TEST MANAGER

CMSgt Lawrence Milano

Chief Milano has 21 years of aircraft flightline and in-shop maintenance experience on F-4C, KC-135A, FB-111, T-37, T-38, F-5, and B-2 aircraft. He has worked as a Jet Engine Technician, Jet Engine Instructor, Production Superintendent, Test Director, and Flight Chief. Assignments include Holloman AFB NM, Kadena AB Japan, Moody AFB GA, Plattsburgh AFB NY, Williams AFB AZ, Edwards AFB CA, and Fort Dix NJ. His education includes a Bachelor of Science in Aviation Management from Embry-Riddle Aeronautical University; two Associates of Applied Science Degrees from CCAF; and an Associate of Applied Science Degree from Rio Salado Community College. He also holds a Federal Aviation Administration Airframe and Powerplant License, and a Department of Defense Level I Acquisition Logistics Certification.

AEROSPACE SYSTEMS LOGISTICS TEST SUPERINTENDENT

SMSgt Michael Corson

SMSgt Corson has 21 years of aircraft flightline and in-shop maintenance experience on B-52G, C-130E, C-141B, KC-135A/R aircraft. He has worked as a Pneudraulic Technician, Pneudraulic Shop Chief, Specialist Flight Chief, Production Superintendent, and Sortie Generation Flight Chief. Assignments include Pope AFB NC, Griffiss AFB NY, McGuire AFB NJ, and Fort Dix NJ. His education includes an Associate in Applied Science Degree from CCAF and he is a graduate of the Strategic Air Command Maintenance University, Carswell AFB TX. He also holds a Federal Aviation Administration Airframe and Powerplant License, and a Department of Defense Level I Acquisition Logistics Certification.

AIRCRAFT COMMUNICATIONS AND NAVIGATION LOGISTICS SUPERINTENDENT

SMSgt Timothy Lucas

SMSgt Lucas has 13 years of aircraft flightline and in-shop maintenance experience on C-130, C-135, C-21, EC-135, HH-53, and T-33 aircraft. He has worked as a Navigation Specialist, Navigation Shop Chief, Project Speckled Trout Communication and Navigation Technician, Project Speckled Trout Communication and Navigation NCOIC, and Project Speckled Trout Avionics Shop Chief. Assignments include Hickam AFB HI, Andrews AFB MD, Edwards AFB CA, and Fort Dix NJ. His education includes a Bachelor of Science Degree from Concord College WV and an Associate in Applied Science Degree from CCAF. He also holds a Department of Defense Level I Acquisition Logistics Certification.

AIRCRAFT GUIDANCE AND CONTROL LOGISTICS SUPERINTENDENT

MSgt Michael Quinn

MSgt Quinn has 15 years of aircraft flightline and in-shop maintenance experience on B-52G/H, KC-10, and KC-135A aircraft. He has worked as an Autopilot Specialist, Autopilot Shop Chief, Guidance and Control Technician, Guidance and Control Shop Chief, Maintenance Expediter, and Production Superintendent. Assignments include Grand Forks AFB ND, Griffiss AFB NY, McGuire AFB NJ, and Fort Dix NJ. His education includes an Associate Degree in Applied Science from CCAF and he holds a Department of Defense Level I Acquisition Logistics Certification.

AIRCRAFT ELECTRO-ENVIRONMENTAL LOGISTICS SUPERINTENDENT

MSgt Daniel Romano

MSgt Romano has 14 years of aircraft flightline and in-shop maintenance experience on B-52H, C-130, C-141, KC-10, KC-135Q, RF-4C, SR-71, T-38, TR-1, and U-2R aircraft. He has worked as an Electrical Systems Specialist, Electro-Environmental Technician, Electro-Environmental Shop Chief, Element Chief, and Quality Assurance Inspector. Assignments include McChord AFB WA, Osan AB ROK, Beale AFB CA, Griffiss AFB NY, McGuire AFB NJ, and Fort Dix NJ. His education includes an Associate Degree in Applied Science from CCAF and he holds a Department of Defense Level I Acquisition Logistics Certification.

AIRCRAFT MAINTENANCE LOGISTICS SUPERINTENDENT

MSgt Kenneth Hadley

MSgt Hadley has 12 years of aircraft flightline maintenance experience on C-130 aircraft. He has worked as a C-130 Crew Chief, Resources and Mobility Branch Superintendent, and C-130 Test Director. Assignments include Little Rock AFB AR, Rhein-Main AB GE, and Fort Dix NJ. His education includes an Associate Degree in Applied Science from CCAF and he holds a Federal Aviation Administration Private Pilot License.

AIRCRAFT PNEUDRAULIC SYSTEMS LOGISTICS SUPERINTENDENT

MSgt Thomas Moriarty

MSgt Moriarty has 15 years of aircraft flightline and in-shop maintenance experience on C-5A/B, C-130, C-141B, KC-10, and T-39 aircraft. He has worked as an Aircraft Pneudraulic Technician, Maintenance Expediter, Element Chief, Maintenance Qualification Training Instructor, and Logistics Training Flight Superintendent Assignments include Norton AFB CA, Rhein-Main AB GE, Barksdale AFB LA, McGuire AFB NJ, and Fort Dix NJ. His education includes two Associates in Applied Science Degrees from CCAF and he also holds a Federal Aviation Administration Airframe and Powerplant License.

HOW TO CONTACT US

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MSgt Hadley	*hadleyk@mcguire.af.mil*	EXT 365
MSgt Moriarty	*moriartt@mcguire.af.mil*	EXT 366

CURRENT TESTS

TEST TITLE:	**KC-135 Air Refueling Pump Test**
AMC TEST NUMBER:	**26-280-96-1**
TEST DIRECTOR:	**SMSgt Corson**
TEST UNIT(S)(S)/LOCATION(S):	**412 TW (AFMC) / Edwards AFB CA** **141 ARW (ANG) / Fairchild AFB WA** **434 ARW (AFRC) / Grissom ARB IN** **108 ARW (ANG) / McGuire AFB NJ** **163 ARW (ANG) / March ARB CA**

TEST TITLE:	**C-5 Main Landing Gear Roll Pin Retention Bolt**
AMC TEST NUMBER:	**26-287-96**
TEST DIRECTOR:	**SMSgt Corson**
TEST UNIT(S)/LOCATION(S):	**60 AMW / Travis AFB CA** **436 AW / Dover AFB DE**

TEST TITLE:	**C-5 Main Landing Gear Strut Scraper Ring**
AMC TEST NUMBER:	**26-293-97**
TEST DIRECTOR:	**SMSgt Corson**
TEST UNIT(S)/LOCATION(S):	**60 AMW / Travis AFB CA** **436 AW / Dover AFB DE** **439 AW (AFRC) / Westover ARB MA**

TEST TITLE:	**ESPA French Drogue Hose on KC-135**
AMC TEST NUMBER:	**26-295-97**
TEST DIRECTOR:	**SMSgt Corson**
TEST UNIT(S)/LOCATION(S):	**100 ARW (USAFE) / RAF Mildenhall UK**

TEST TITLE:	**KC-135 Air Cycle Machine**
AMC TEST NUMBER:	**26-268-94**
TEST DIRECTOR:	**Capt Greco**
TEST UNIT(S)/LOCATION(S):	**22 ARW / McConnell AFB KS** **128 ARG (ANG) / General Mitchell IAP WI** **161 ARG (ANG) Sky Harbor IAP AZ**

TEST TITLE:	**C-141 Digital Fuel Quantity Indicating System**
AMC TEST NUMBER:	**1-60-90**
TEST DIRECTOR:	**MSgt Quinn**
TEST UNIT(S)/LOCATION(S):	**305 AMW / McGuire AFB NJ** **445 AW (AFRC) / Wright-Patterson AFB OH** **164 AW (ANG) / Memphis IAP TN**

TEST TITLE:	**C-5 Aircraft Hydraulic Motor Magnetic Seals**
AMC TEST NUMBER:	**26-284-96**
TEST DIRECTOR:	**MSgt Romano**
TEST UNIT(S)/LOCATION(S):	**436 AW / Dover AFB DE** **105 AW (ANG) / Stewart IAP NY**

TEST TITLE:	**Ground Support H-1 Heater Assembly**
AMC TEST NUMBER:	**26-278-96**
TEST DIRECTOR:	**MSgt Romano**
TEST UNIT(S)/LOCATION(S):	**5 BW (ACC) / Minot AFB ND** **354 FW (PACAF) / Eielson AFB AK** **388 FW (ACC) / Hill AFB UT**

TEST TITLE:	**C-5 Anti-skid Detector Hub Assembly**
AMC TEST NUMBER:	**26-296-97**
TEST DIRECTOR:	**MSgt Romano**
TEST UNIT(S)/LOCATION(S):	**60 AMW / Travis AFB CA**

TEST TITLE:	**C/KC-135 MLG Copper Beryllium Axle Bushing**
AMC TEST NUMBER:	**26-299-97**
TEST DIRECTOR:	**Capt Thomas**
TEST UNIT(S)/LOCATION(S):	**168 ARW (ANG) / Eielson AFB AK**

TEST TITLE:	**C/KC-135 Main Landing Gear Axle Sleeve**
AMC TEST NUMBER:	**26-294-97**
TEST DIRECTOR:	**Capt Thomas**
TEST UNIT(S)/LOCATION(S):	**121 ARW (ANG) / Rickenbacker IAP OH**

TEST TITLE:	**KC-135 Hydraulic Reservoir Check Valve**
AMC TEST NUMBER:	**26-303-97**
TEST DIRECTOR:	**MSgt Romano**
TEST UNIT(S)/LOCATION(S):	**436 AW / Dover AFB DE** **105 AW (ANG) / Stewart IAP NY**

TEST TITLE:	**PALL Portable Fluid Purifier**
AMC TEST NUMBER:	**26-305-97**
TEST DIRECTOR:	**SMSgt Lucas**
TEST UNIT(S)/LOCATION(S):	**62 AW / McChord AFB WA**

TEST TITLE:	**Helicopter Ground Handling Wheels**
AMC TEST NUMBER:	**26-308-97**
TEST DIRECTOR:	**Capt Thomas**
TEST UNIT(S)/LOCATION(S):	**89 AW / Andrews AFB MD**

TEST TITLE:	**C-5 EQUAL Tire Balancing Compound**
AMC TEST NUMBER:	**26-309-97**
TEST DIRECTOR:	**MSgt Quinn**
TEST UNIT(S)/LOCATION(S):	**60 AMW / Travis AFB CA**

TEST TITLE:	**Modified C-130 Nose Radome**
AMC TEST NUMBER:	**26-301-96**
TEST DIRECTOR:	**MSgt Hadley**
TEST UNIT(S)/LOCATION(S):	**314 AW (AETC) / Little Rock AFB AR** **347 W (ACC) / Moody AFB GA** **302 AW (AFRC) / Peterson AFB CO** **109 AW (ANG) / Schenectady Cty Airport NY**

TEST TITLE:	**C-130 Brake Piston Insulator**
AMC TEST NUMBER:	**26-310-97**
TEST DIRECTOR:	**MSgt Hadley**
TEST UNIT(S)/LOCATION(S):	**314 AW (AETC) / Little Rock AFB AR**

TEST TITLE:	**KC-135 Fuel Boost Pump and Override Pump**
AMC TEST NUMBER:	**26-311-98**
TEST DIRECTOR:	**MSgt Moriarty**
TEST UNIT(S)/LOCATION(S):	**128 ARW (ANG) / General Mitchell IAP WI** **171 ARW (ANG) / Pittsburgh IAP PA**

TEST PUBLICATIONS

Departmental Publishing Electronic Publications. All of the following publications can be found on the Internet at: http://afpubs.hq.af.mil/elec-products/pubs-pages.

Air Mobility Command

AMCI 99-101 Operational Test and Evaluation. Provides guidance and procedures for operational test and evaluation (OT&E) in the Air Mobility Command (AMC). It applies to all AMC agencies and AMC-assigned elements of the Air Force Reserve Command and the Air National Guard (ANG) when published in the ANG Index 2. This instruction describes how to plan, conduct, and report on AMC-initiated/conducted OT&E.

Air Force

AFI 10-602 Determining Logistics Support and Readiness Requirements. Provides a framework for defining readiness and logistics support requirements throughout the system acquisition or modification process. Attachment 1 defines terms commonly used in test. Attachment 2 lists the integrated logistics support elements. Attachment 3 thru 10 lists the various types of measures and formulas used for test.

AFI 21-101 Maintenance Management of Aircraft. This is the basic Air Force direction for aircraft maintenance management. Chapter 2, paragraph 2.14, **Modification Management**, defines Air Force policies and procedures for accomplishing aircraft modifications and defines the three classes of modifications. Paragraph 2.14.1.2, defines Temporary-2 (T2) Modifications. The most commonly used modification in OT&E is the T-2 modification. Paragraph 2.14.7 specifically outlines the procedures for initiating and completing an **AF Form 1067, Modification Proposal.** Most modified components and/or systems require an approved AF Form 1067 prior to executing an OT&E.

AFI 36-2201 Developing, Managing, and Conducting Training. Assigns responsibilities, and provides guidance and procedures for developing, managing, and conducting Air Force technical, ancillary, and recruit training. Chapter 11 specifically describes organizational responsibilities for funding, managing, and administering special training during test.

AFI 99-101 Developmental Test and Evaluation. Provides mandatory procedures for the management of developmental test and evaluation programs on systems, subsystems, and components.

AFI 99-102 Operational Test and Evaluation. Provides guidance and procedures for operational test and evaluation (OT&E) in the Air Force. It applies to all agencies involved in or supporting OT&E. It describes how to prepare, plan for, and report on operational test.

AFI 99-103 Test and Evaluation Process. This instruction directs and describes the Air Force Test and Evaluation Process and its relationship to the systems acquisition process.

AFI 99-109 Test Resource Planning. This instruction defines test resources, the test resource planning process, test resource usage, and responsibilities associated with test resources.

AFMAN 99-110 Airframe-Propulsion-Avionics (A-P-A) Test and Evaluation Process Manual. A guide for program managers, test managers, test engineers, test organization personnel, major command headquarters staffs, and others involved in test and evaluation of A-P-A mission area systems.

AIR FORCE OPERATIONAL TEST AND EVALUATION CENTER (AFOTEC)

AFOTEC HANDBOOK 99-101 Test Management and Policy Handbook. This handbook is intended to serve as a definitive guide for test managers, test directors, test teams, and test support groups to obtain the necessary expertise to accomplish a thorough, credible OT&E.

AFOTEC PAMPHLET 99-104 Operational Suitability Test and Evaluation. This publication tells how to develop the operational suitability test and evaluation portion of the test concept, test plan, and final report. It provides definitions of common terms and measures, identifies processes related to suitability test and evaluation, and provides examples of structuring a test to answer the question "Is the system suitable?"

INTEGRATED LOGISTICS SUPPORT (ILS) ELEMENTS

ILS is a composite of all support necessary to ensure effective, economical support of a system throughout its life cycle. OT&E, in general, is the primary source of ILS data. User tests are conducted in a realistic environment with personnel representative of those who will eventually operate and maintain the fielded system. The main objective of ILS OT&E is to verify that the logistic support for the system is capable of meeting required objectives. The following ten specific ILS elements must be considered during test planning.

1. Design Interface. Consider:

- Standardization of components, hardware, software, fuel, lubricants, and other materials
- Interoperability with existing systems and subsystems
- Human factors
- Maintainability
    - Accessability
    - Serviceability
- Safety
- Support equipment
- Test and diagnostic equipment
- Metrology and calibration equipment
- Transportability

2. Maintenance Planning. Consider:

- Repair levels
- Repair times
- Requirements and constraints inherent in on-equipment maintenance
- Requirements and constraints inherent in off-equipment maintenance
- Contractor support
- Peacetime operation
- Wartime operation
- Contingency operations
- Facility requirements
- Supply

3. Support Equipment (SE). Consider:

- Transportation, ground handling, and maintenance equipment
- Reliability
- Maintainability
- Availability
- Transportability
- Maneuverability
- Special and common tools
- Test and diagnostic equipment
- Metrology and calibration equipment
- Aircraft battle damage repair kits
- Software support and reprogramming equipment
- Computer programs

4. Supply Support. Consider:

- Maintenance concepts
- Operations tempo
    - Peacetime operation
    - Wartime operation
    - Contingency operation
- Primary operating stock
- Readiness spares support concepts
- Component availability
- Component reliability
- Component criticality
- Deployability
- Days of support without resupply
- Peculiar mission requirements of each organization

5. Packaging, Handling, Storage, and Transportation (PHS&T). Consider:

- Capability of personnel to package, transport, preserve, protect, and properly handle all systems, equipment, and support items.
- Geographical restrictions
- Environmental restrictions
- Electrostatic discharge-sensitive equipment requirements
- Hazardous material requirements.
- Standard handling equipment and procedures
- Capability of existing commercial or military transportation systems and facilities to accommodate gross weights and dimensions
- Capability of the Container Design Retrieval System to provide suitable existing containers

6. Technical Data. Consider:

- Contractor validated manuals (TO 00-5-3, Chapter 8)
- Air Force verified manuals (TO 00-5-3, Chapter 9)
- Adequate notes, cautions, and warnings
- Minimum cross-referencing between manuals
- Capability of technical data or commercial manuals to support, operate, and maintain systems and equipment in the required state of readiness
- Capability of backup methodologies for archiving technical data to protect it from destruction during disasters

7. Facilities. Consider:

- Design
    - Workspace requirements
    - Utilities requirements
- Safety
- Security
- Normal and special environmental requirements and controls
- Personnel and equipment protective systems
- Hazardous materials handling and disposal

8. Manpower and Personnel. Consider:

- Air Force specialty codes, skill levels, and number of personnel required to maintain, repair, and operate systems and equipment
- Safety and health hazards
- Effect of planned workloads on operators and maintenance personnel in the operational environment

9. Training and Training Support. Consider:

- ♦ Aircrew training
- ♦ Operator training
- ♦ Maintenance training
    - ♦♦ On-equipment
    - ♦♦ Off-equipment
- ♦ Mockups, simulators, training aids, and computer based training systems
- ♦ Initial, formal, on-the job, and contractor training (AFI 36-2201)

10. Computer Resources Support. Consider:

- ♦ System requirements
- ♦ Design constraints
    - ♦♦ Spare memory
    - ♦♦ Computer memory growth
    - ♦♦ Modular design
    - ♦♦ Software module size
- ♦ Interface capability with existing systems
- ♦ Necessary documentation
- ♦ Related software
- ♦ Software reprogramming requirements
- ♦ Source data
- ♦ System security
- ♦ Facilities
- ♦ Hardware
- ♦ Firmware
- ♦ System reliability
- ♦ System maintainability
- ♦ Manpower
- ♦ Personnel
- ♦ Human-machine interface
- ♦ Operational environment